TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

VOL. IX. JUNE AND SEPTEMBER, 1896. NO. 2–3.

PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-FOURTH YEAR, 1895–96.

THURSDAY, April 9, 1896.

THE 485th meeting of the SOCIETY OF ARTS was held at the Institute on this day at 8 P.M., Professor H. P. Talbot in the chair.

The record of the last meeting was read and approved. The Secretary reported that the Executive Committee had approved the following nominations for associate membership: Macy S. Pope, of Boston; Edward D. Brown, of New York; Howard C. Forbes, of Boston; Parker C. Newbegin, of Houlton, Maine; Albert H. Sawyer, of Boston; George W. Sherman, of Cambridge; George R. Underwood, of Peabody; Hans Birkholz, of Milwaukee, Wisconsin; Edward P. Boone, Jr., of Boston; and John F. Low, of Chelsea. These nominees were duly elected. The Secretary announced the receipt of invitations to the exhibition of the Camera Club.

The President then introduced Mr. Arthur D. Little, of Boston, who read a paper on "Paper and Paper Testing." The various classifications of paper by composition and by physical properties were given. Precautions required in testing were discussed, and then the various methods of testing paper were described, and many of them

were illustrated by experiments. At the close of his remarks Mr. Little exhibited a remarkable collection of very rare and beautiful Russian water markings.

A discussion followed, and then, after the speaker had been thanked for his very interesting paper, the Society adjourned.

THURSDAY, April 23, 1896.

The 486th meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., Professor Allen in the chair.

The record of the last meeting was read and approved. On motion, it was voted to authorize the President to appoint a committee to nominate candidates for election to the Executive Committee for the next year.

Major W. R. Livermore, of the United States Engineers, was then introduced and read a paper on the "Arts and Sciences in the Twentieth Century." The immense accumulation of knowledge at the present time was dwelt upon, and it was pointed out that there is need of coöperation between the different branches of science. For this a common language is necessary, and the graphic methods of presenting facts were shown to be capable of wide application in this connection. A number of charts and tables were exhibited by means of the lantern to illustrate points made in the paper.

A discussion followed, after which the speaker was thanked by the chair for his very interesting and suggestive paper, and the Society adjourned.

THURSDAY, May 14, 1896.

The 34th annual meeting (487th meeting) was held at the Institute on this day at 8 P.M., the President in the chair and a quorum of members present.

The record of the previous meeting was read and approved.

Mr. Lowe presented the report of the Nominating Committee, recommending for the Executive Committee for the next year Messrs. George W. Blodgett, Percival Lowell, Henry M. Howe, Walter S. Allen, and Desmond FitzGerald.

Mr. Woodbury, of the Executive Committee, reported that the committee nominated Dr. R. P. Bigelow for Secretary for the ensuing year.

The reports were accepted, the Society proceeded to ballot, and these gentlemen were declared duly elected.

Mr. Woodbury read the report of the Executive Committee as follows in part:

The Executive Committee of the SOCIETY OF ARTS presents as its annual report for the 34th year the following:

MEMBERSHIP.

Life members May, 1895		71
Became life members by operation of the By-Laws		2
		73
Died during the year		6
Life members at the present time		67
Number of associate members May, 1895		181
Number of associate members elected during the year		118
		299
Died	2	
Resigned	5	
Dropped for non-payment of dues	1	
Transferred to life membership	2	
		10
Present number of associate members		289

MEETINGS.

Including the present meeting, thirteen have been held during the year, at which fourteen papers will have been read. As all of these (with three exceptions) have been, or will shortly be, published in the TECHNOLOGY QUARTERLY it is not thought necessary to recapitulate them here. Thirteen papers published in the QUARTERLY have been read by title.

Three addresses illustrating original work of the speakers are especially worthy of mention, viz.: The paper read January 9 on "A New Method of Studying the Light of Alternating Arc Lamps," by Professor W. L. Puffer, of the Institute; the exhibition given by Mr. Louis Derr, of the Institute, February 13, of "Apparatus for Showing the Phase Relations of Alternating Currents;" and the demonstration given by Professor Cross on the same evening of Professor Röntgen's X-Rays.

The Executive Committee would be much gratified if members having important information of a scientific or practical character would communicate with the Secretary with a view to its being brought before the Society; also if they would make more widely known among their friends the scope and purpose of the Society, and thus add to the attendance and to the interest of the meetings.

(Signed) FRANCIS A. WALKER,
GEORGE W. BLODGETT,
HENRY M. HOWE,
C. J. H. WOODBURY,
ROBERT P. BIGELOW,
Of the Executive Committee.

The report was accepted and ordered placed on file. The Secretary read the report of the Meteorological Committee as follows:

The undersigned members of the Meteorological Committee beg leave to report that they have watched with interest the development of the work of the Boston Station of the Weather Bureau, which is still in charge of Mr. J. W. Smith. The improved method of printing the Daily Weather Maps, proposed by Mr. Smith and mentioned in last year's report, has been put in practice, and Mr. Smith will introduce the process in other cities by order of the chief of the bureau. Briefly described, the isobars and isotherms with the necessary explanatory figures are engraved at the station on a metal plate representing the base maps of the United States. From a stereotype of this the maps are printed, together with tabular matter and predictions set in type. Large editions of the maps are printed more quickly than were the former cyclostyle copies, and although the present map is smaller in size, it is more legible.

Another innovation during the year has been the introduction of special hurricane signals. For night signals more powerful electric lights than heretofore are now displayed and at a greater height above the post office tower, thereby rendering them less likely to be mistaken by mariners for other lights.

The committee have to announce that the Monthly Bulletin of the New England Weather Service has given place to a similar Climate and Crop Report, which it is the intention of the chief to issue in place of the existing State Weather Service Bulletins. A uniform method of publishing meteorological data throughout the United States is highly desirable, and it is a compliment to J. Warren Smith that the observations under his direction in New England should be the first to be published in the new form.

(Signed) WILLIAM H. NILES, A. LAWRENCE ROTCH, } *Meteorological Committee.*

The report was accepted and ordered placed on file.

The following gentlemen were elected associate members: George Wyman Hamilton, of Boston; Fred F. Moore, of South Framingham; G. W. Patterson, Jr., of Ann Arbor, Michigan; Walter W. Reed, of Waltham; and A. Forrest Shattuck, of Syracuse, New York.

The following papers (published in the present number of the QUARTERLY) were presented by title: "Englacial Drift," by W. O. Crosby; "Notes on the Best Form of Cross Section for the Coils of a Galvanometer," Part I, by F. A. Laws; and "Some Experiments on the Growth of Diatoms," by G. C. Whipple.

The President then introduced Mr. Horace See, of New York, who read a paper on the "Recent Development of Large Freight Steamers." The paper was illustrated by means of views and plans thrown upon the screen by the lantern. First, the development of

freight steamers from their beginning to the present was sketched; then the recent improvements in large freight steamers were described, especially the important improvements in the machinery, resulting in greater economy of space and of fuel.

At the close of the paper the President thanked the speaker, and the Society adjourned.

ROBERT PAYNE BIGELOW, *Secretary.*

DESCRIPTION AND COMPUTATION OF A TWENTY-FOUR HOUR DUTY TEST ON THE TWENTY MILLION GALLON LEAVITT PUMPING ENGINE AT CHESTNUT HILL.

RESULTS OF TESTS MADE IN THE ENGINEERING LABORATORIES.

IV.

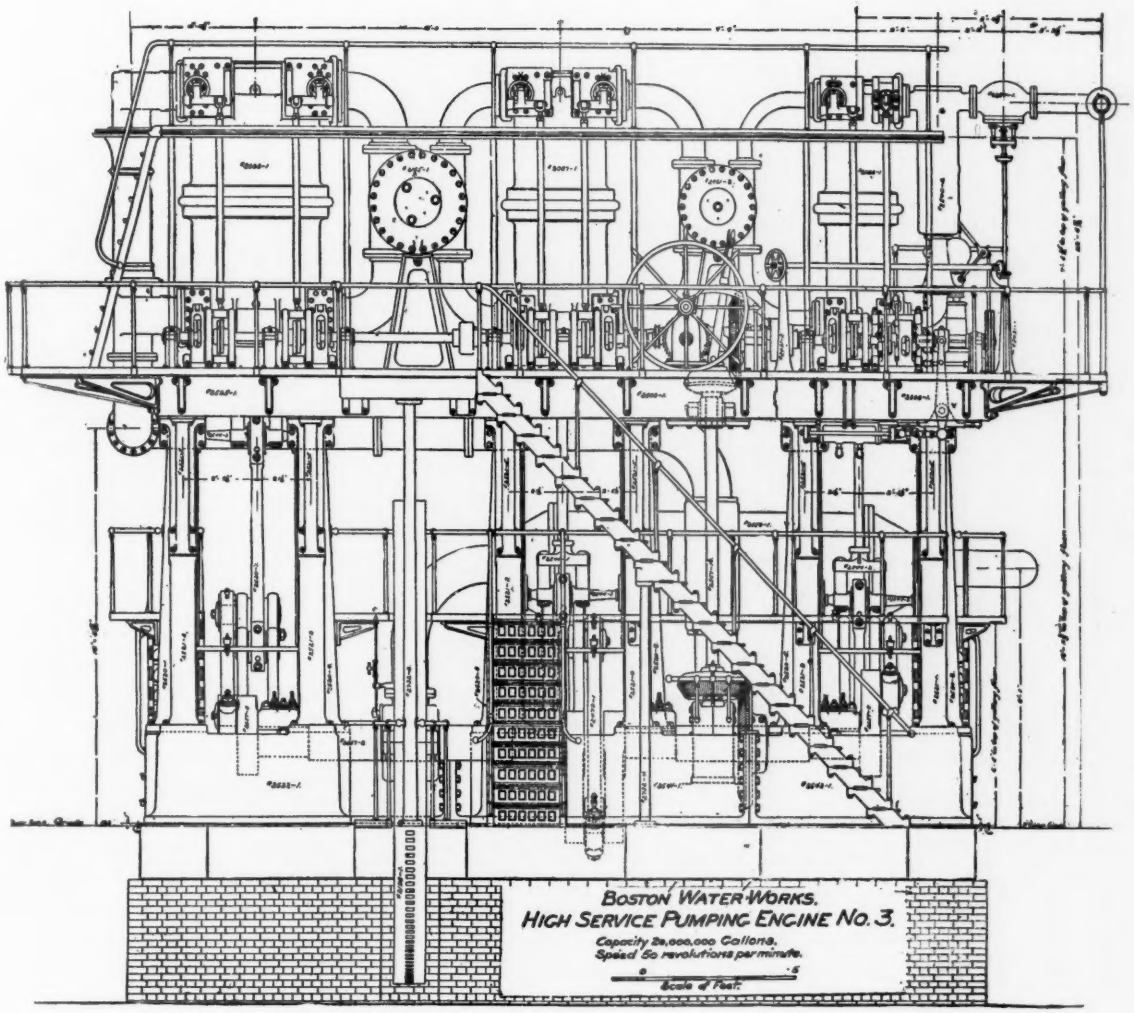
BY EDWARD F. MILLER, S.B.

Read March 12, 1896.

THE test which I am about to speak of was made on May 1st and 2d of last year by about ninety students of the senior class of the Massachusetts Institute of Technology. The test formed a part of the regular work of the Engineering Laboratories, and was made under the direction of the laboratory instructing staff. The following brief description of the engine and boiler is taken from the 1894 report of the City Engineer, Mr. William Jackson.

The engine (Plate 1) was built by the Quintard Iron Works of New York, from designs furnished by E. D. Leavitt, of Cambridge. It is a triple expansion, three-crank rocker engine, with pistons 13.7, 24.375, and 39 inches in diameter and 6 foot stroke. The cylinders are vertical and inverted, and are carried, together with valve gear, on an entablature supported by six vertical and six diagonal columns. The steam and exhaust valves are gridiron slides worked by cams on a horizontal shaft, which is driven by gearing from the crank shaft. The cut-off of the high pressure cylinder is regulated by the governor through the agency of a hydraulic cylinder, which advances or retards the cut-off cam by means of a spiral sleeve; the cut-offs of the other engines are fixed. The steam passes into the high pressure cylinder through a separator forming a part of the inlet side pipe. After expanding in this cylinder it passes through a tubular reheater to the intermediate cylinder, and thence through another similar reheater to the low pressure cylinder. The reheaters have steam of boiler pressure, or about 185 pounds per square inch on the inside of the tubes, and the working steam on the outside. All the cylinders are steam-jacketed on

PLATE I.


BOSTON WATER WORKS.
HIGH SERVICE PUMPING ENGINE NO. 3.
Capacity 24,000,000 Gallons.
Speed 20 revolutions per minute.
0
5
Scale of Feet.

the head and barrels, the low pressure cylinder with steam at 100 pounds and the others at 185 pounds. The jackets and reheaters using steam of boiler pressure are drained back to the boiler, while the low pressure cylinder jackets and the working steam side of the reheaters are drained by means of automatic traps discharging into the hot well.

The engine crossheads work on guides cast in the vertical columns. The motion is transmitted from the crossheads by links to beams or rockers carried in pedestals on the bedplate of the engine. From these beams the connecting-rods work off in one direction and the pump links in the opposite direction, but inclined at an angle of about 30 degrees from the horizontal. The leverage of the various pins in the beams is such that the stroke, which is 6 feet in the case of the steam pistons, is reduced to 4 feet for the pump plungers, which is also the amount of the double throw of the cranks. The crank shaft has three cranks set at angles of 120 degrees, the low pressure crank leading, followed by the intermediate and high pressure cranks. The shaft is carried in four adjustable four-box pedestals, with overhung end cranks. Between two of these pedestals is the fly-wheel, and between the other two the gear for driving the cam shaft.

There are three double-acting inclined pumps (Plate 2), having plungers 17.5 inches in diameter and 4 feet stroke. The pumps are seated on foundations at a lower level than those for the engines, the pump chambers being tied to the engine bedplates by horizontal girders, as well as by the pump crosshead guides, which are inclined 30 degrees from the horizontal. This peculiar arrangement of inclined pumps was found necessary to suit existing conditions of engine house, pump well, etc. The pump bases or suction chambers, six in number, one for each end of each pump, are connected together, and the bases of each pump are connected by a separate suction pipe. The lower or working pump chambers are surrounded by annular spaces throughout their height, forming vacuum chambers. The upper pump chambers contain the delivery nozzles, and above these are the air chambers, all six of the latter being connected by pipes.

Each end of each pump has one suction and one delivery valve, consisting of a number of rigidly connected rings covering annular openings in the valve seats. The speed necessary for the required capacity of 20,000,000 gallons in twenty-four hours is fifty revolu-

tions per minute, but the engine has been designed to run easily at sixty revolutions per minute. The head pumped against is 128 feet, or about 55 pounds per square inch.

Each pump contains one suction and one delivery valve, each about 3 feet in diameter. The use of these large valves, together with the phenomenally high speed, is made possible by the method of working the pump valves, which is the invention of Professor Riedler, of the Royal Polytechnic School, of Berlin, Germany. This invention consists in closing each valve positively at just the moment of reversal of stroke by means of levers and rods. After closing the valves the mechanism moves out of the way, leaving the valves free to open automatically.

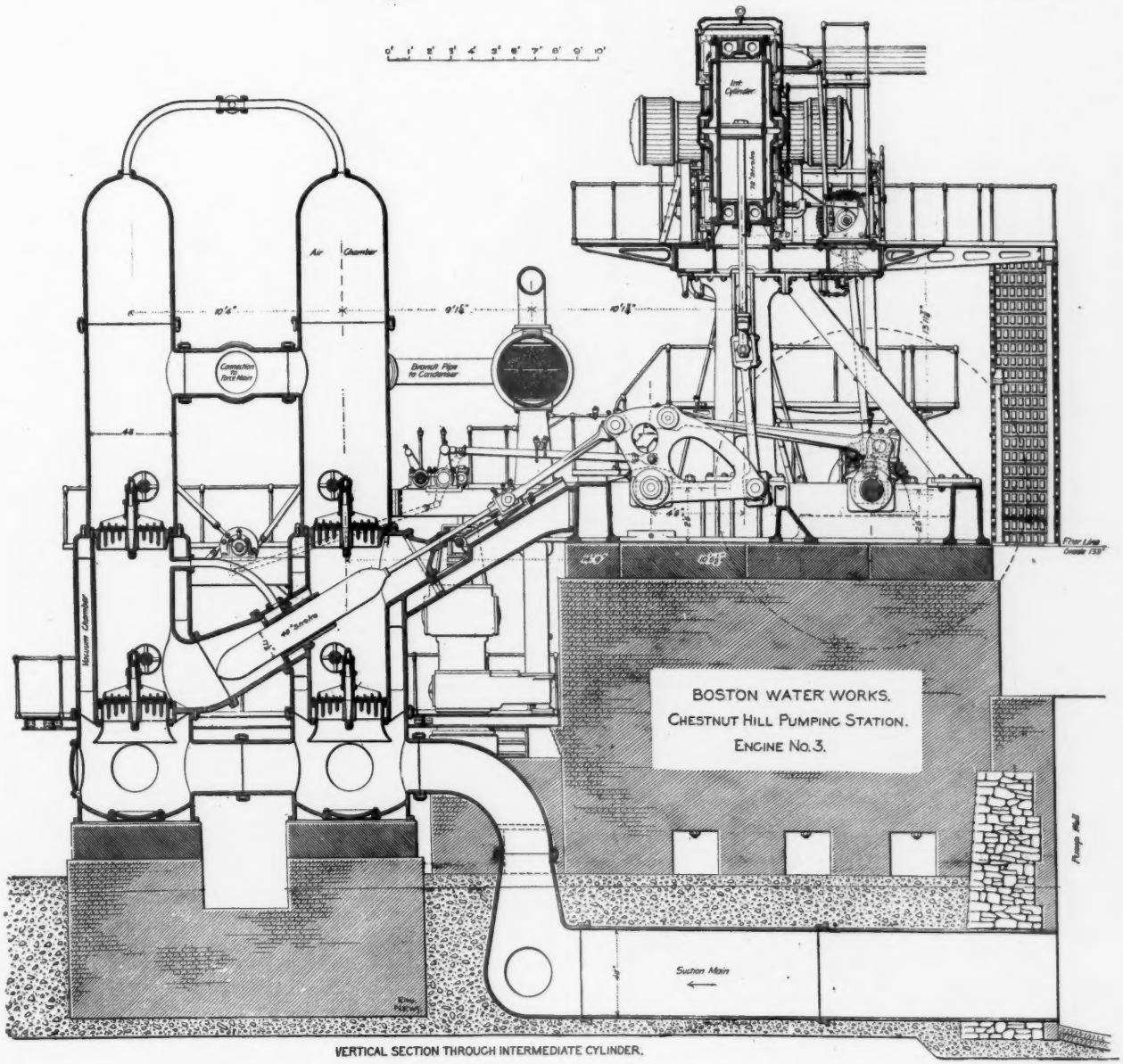
Although the design for the Chestnut Hill engine was begun first, the large pumping engine of the Bethlehem Iron Company, also of Mr. Leavitt's design, was the first Riedler engine in operation in this country, having been started more than a year before the Boston engine. There are now quite a number of Riedler engines in this country, some running as fast as 120 revolutions per minute.

The condenser of the Chestnut Hill engine is of the surface type, having 1,410 square feet of tube surface, with water passing through the tubes. The condensing water is taken from one of the upper pump chambers, and after passing through the condenser is delivered into the force main. A butterfly valve in one of the pump discharge pipes permits the quantity of condensing water to be easily regulated. The air pump is of the single-acting bucket type, 24″ diameter and 12-inch stroke, situated directly below the condenser, and worked by an arm on one of the pump valve gear rocker shafts.

Steam for the engine is furnished by a Belpaire fire-box boiler (Plate 3) having two separate furnaces and a common combustion chamber. The boiler is 34 feet 4 inches long, with a least internal diameter of shell of 90 inches. The tubes are 201 in number, 3 inches in diameter, and 16 feet long. The feed water, before entering the boiler, passes through a Green economizer, where it is heated by the escaping gases.

Arrangements and Changes Made for the Test.

The air pump ordinarily delivered into a closed hot well, into which the drips from the separator and from the working sides of the first and second receivers were discharged. The steam used by the feed



VERTICAL SECTION THROUGH INTERMEDIATE CYLINDER.

FIG.1

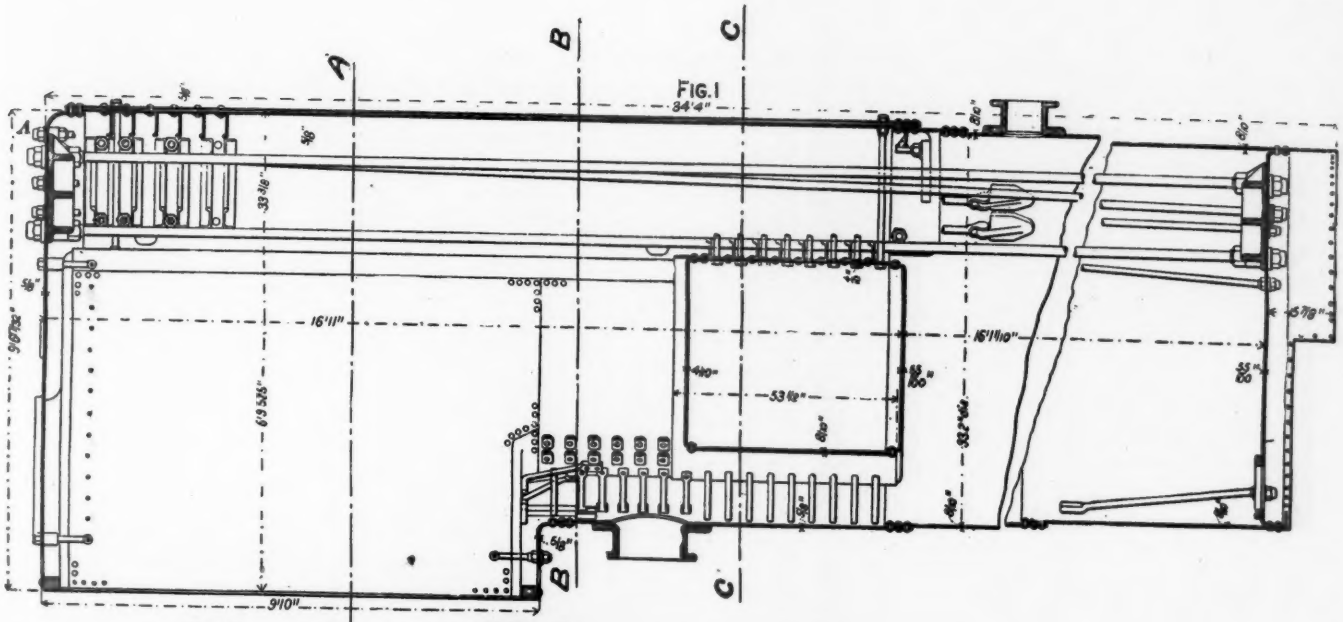
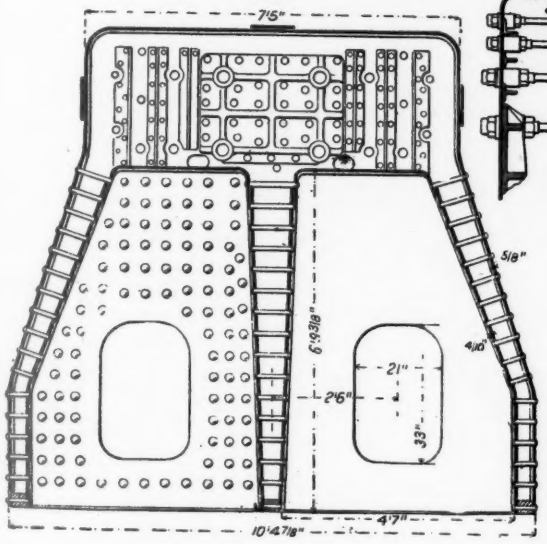


FIG.2



SECTION AA LOOKING FRONT.

FIG.5

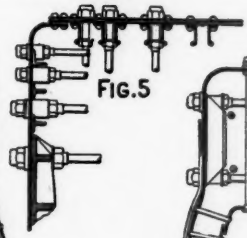
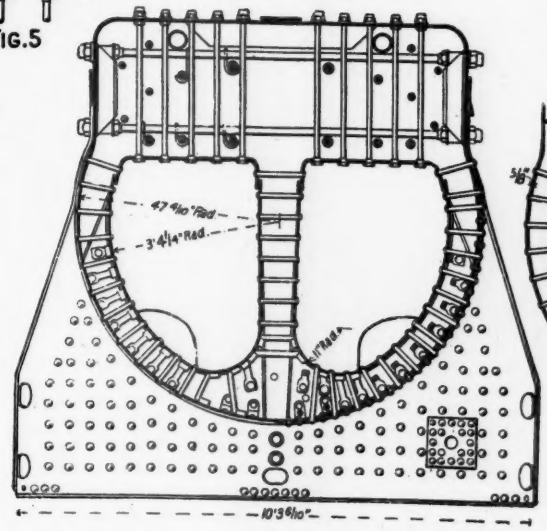
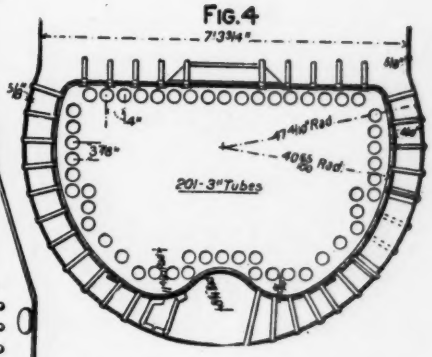


FIG.3



SECTION BB LOOKING FRONT.

FIG.4



SECTION CC LOOKING BACK

pump and the small hydraulic pump, supplying oil for the hydraulic cylinder used in governing the cut-off on the high pressure engine, was also exhausted into this hot well. Ordinarily, whatever make-up was needed to supply losses was put into the hot well.

The regular feed pump (Fig. 1) *A*, which at that time was under the engine close to the hot well, took its supply from the hot well *B*. In order to weigh the air pump discharge, the piping leading from the air pump to the hot well was broken and led over to two weighing barrels *C* and *D*, each of about 1,200 pounds capacity. From a tee at the

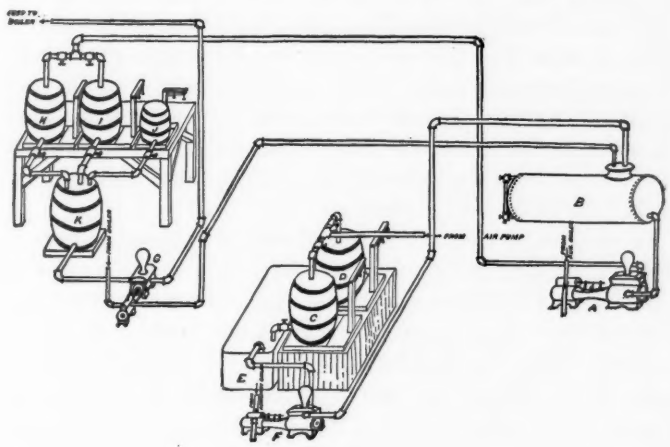


FIG. 1.

end of the air pump discharge, a branch with valve ran to each barrel, thus enabling the water to be run into first one barrel and then the other. These two barrels discharged into an open iron tank *E* of about 1,000 pounds capacity. The drips from the separator from the working sides of the first and second receivers and from the low pressure jacket were discharged after being measured into the bottom of this tank. An auxiliary pump *F*, supplied with steam from an auxiliary boiler, pumped the water from this tank into the hot well *B*. The pump *A* was disconnected from the boiler at both steam and water ends. Steam was supplied by an auxiliary boiler. It was used during the test to pump the water from the hot well to the weighing barrels *H* and *I* in the boiler room.

At first sight it might seem that there was unnecessary piping, but there appeared to be no other way of separating the different weights and at the same time getting the benefit of the heat in the exhaust steam from the feed and oil pumps. The barrels *H* and *I* were arranged similar to the barrels *C* and *D*. In these was weighed the water from the air pump plus the drips from the separator, the working sides of the first and second receivers and the low pressure jacket water, plus also the steam used by the feed pump *G* and the oil pump. The barrels *H* and *I*, together with a small make-up barrel *J* (fed from the water main), delivered into a reserve barrel *K*, from which the feed pump *G* supplied the boiler.

The returns from the high pressure, intermediate pressure, first and second reheater jackets were returned directly to the boiler by gravity, and the total amount of steam used by these was determined by a separate test made immediately after the engine test. No attempt was made to find the amount used by the different high pressure jackets separately.

At the end of the test the pipe conveying these returns to the boiler was broken and the drip turned into a closed steel reservoir about 18 inches in diameter and 9 feet tall. On the side of this reservoir were two gauge glasses, each 4 feet long, and a scale previously graduated, giving the capacity of the reservoir at any level to $\frac{1}{100}$ of a cubic foot. When full, the reservoir could be emptied quickly through a 2-inch globe valve. By noting the rate at which the reservoir filled, allowance could be made for the water lost while blowing out. From the amount caught in eighty minutes the weight for twenty-four hours was calculated.

The returns from the separator from the working sides of the two receivers and from the low pressure jacket were caught during the test in similar reservoirs made of 8-inch pipe. A throttling calorimeter with a $\frac{1}{4}$-inch steam orifice was attached to the steam pipe just before the throttle. A record was kept of the time during which the calorimeter was in use, and the amount of steam used by it was calculated by Napier's formula.

The height of water in the suction well above mean tide marsh level was read by means of a copper float and graduated scale. A scale and gauge glass on the side of one air chamber gave the level in the air chambers above mean tide marsh level. From the top of the air chamber a $\frac{1}{4}$-inch pipe led to one leg of a U tube filled with

mercury. The discharge pressure was calculated from the difference of level of the two legs of mercury. The steam used by the small engine running the scrapers in the Green economizer was run into a barrel of cold water on scales, condensed and weighed. The water pumped was measured at Fisher Hill by a weir without and contractions 10.002 feet in width. Samples of flue gas were taken just above the damper between the boiler and the economizer.

Starting and Ending the Test.

The engine was run at speed for nearly an hour before starting the boiler test. The pressure was run down, and at the time of starting the new fire was 86 pounds by the gauge. As soon as the engine was stopped, the old fire was drawn from the grate and wood previously weighed was thrown in. The boiler test was started at 8–30, the time this wood was ignited, and then the ash-pit was cleaned. As soon as the wood was well on fire, coal was thrown in, that which fell through the grates being taken out and fired again.

At 8–30 levels were noted in the boiler, in the reserve tank *K*, in the boiler room, in the iron tank *E*, into which the air pump discharge was run after being weighed, and in the hot well *B*. At the end of the boiler test these levels were made the same as at starting. At 9–09 A.M., thirty-nine minutes after starting the boiler test, the engine was started; at 9–15 the engine was running smoothly at normal speed, and the 24-hour test was begun. At 9–15 levels were noted in the boiler, in the reserve barrel *K*, in the reservoir *E*, and in the hot well *B*, and a separate record kept of the amount of water required by the boiler for twenty-four hours, and also of the steam used by the engine cylinders in twenty-four hours.

Cards from both ends of steam and water cylinders, and readings of pressures, temperatures, revolutions, etc., were taken at the stroke of a gong every fifteen minutes. Readings at the weir on Fisher Hill were taken at three or five minute intervals. After 9–15, on May 2, the end of the 24-hour engine test, the engine was run in order to drop the pressure in the boiler to that observed at starting. This result was attained at 9–26, when the engine was stopped and the boiler test ended. The fires were drawn and weighed, as were also the ashes. The jackets were in use during the entire boiler test. After ending the boiler test a new fire was built and the engine

started again. The high pressure jacket returns were now cut off from the boiler and measured as previously explained.

A second test was then made with the engine hot but not running, to see what was the rate under these conditions. The amount of drip from the low pressure cylinder jacket was also measured under the same conditions. From the rate as obtained from the second test, the amount of steam made by the boiler before the engine started was figured. The test was divided up into three watches of eight hours, thirty men working at one time. All indicator cards were planimetered and measured during the test. Corrections were determined for all thermometers used during the test. The different steam gauges were compared with an open mercury column both before and after the test. Scales were all tested in position up to 1,000 pounds, with sealed weights.

Remarks.

At the time of the test the engine was new, all bearings were slack, and previous to the test had never been run for more than seven hours consecutively. One of the firemen had never fired the boiler previous to the test, and consequently did not get best results, as is evident from the analysis of the flue gases. The excess of free oxygen shows that the fire was too thin and that too much air was admitted. This extra air carried away considerable heat which might have been saved.

At 2–06 P.M. one of the safety valves blew for four minutes. At 5–15 A.M., on May 2, one of the sections of grate fell out of the left fire-box, and in replacing it two more came out, causing the pressure to fall to 140 pounds. The bars were replaced and full pressure up again by 6 A.M. It was estimated that 200 pounds of extra coal were fired to replace this loss. This estimate was based upon the rate of firing previous to this time. The test was calculated without making any allowance for the estimated 200 pounds excess of coal, and also in items marked with the subscript *a* allowance was made.

One of the joints of the feed pump leaked slightly during the test. As soon as the leak was discovered the leakage was caught and returned to the suction barrel. From the rate of leakage it was estimated that 1,440 pounds were lost before the leak was found. There was a slight leak at the front of the boiler of which no account was taken. After the test it was discovered that there was a leakage by the low pressure piston.

CALCULATION OF BOILER RESULTS.

(A) Quality of steam at throttle.

Throttling calorimeter with a $\frac{1}{4}$-inch steam orifice was used. Calculated by this formula:

$$x = \frac{\lambda + .48\,(t_s - t) - q}{r}.$$

λ = total heat of saturated steam calorimeter pressure.
q = heat of liquid at temperature of entering steam.
r = total latent heat of entering steam.
t_s = temperature °F. by thermometer.
t = temperature of saturated steam at calorimeter pressure.

Time, 11–47.

Boiler pressure absolute after applying correction to gauge = 194.9.

Back pressure in calorimeter (absolute) after applying correction to gauge = 29.9.

Temperature of steam in calorimeter (corrected) = 311.0° F.

r = 845.3	q = 352.4
λ = 1,158.2	t = 250.1
t_s = 311.0	x = .988

Other values of x calculated in same way. .988 is mean of all values.

The total weight of steam used by the calorimeter in 159 minutes was figured from the flow through a $\frac{1}{4}$-inch diameter orifice by means of Napier's formula.

The average absolute boiler pressure was 191 pounds.

$$\text{Total weight} = 1{,}280 = \frac{.25 \times .25 \times .7854 \times 191 \times 159 \times 60}{70}.$$

(B) See (*l*) Boiler Test Data.

(C) Average pressure, 175.7 + 14.8 = 190.5.

Average temperature feed entering economizer = 127° F.

Heat put into one pound = $(xr + q - q)$. (at boiler. feed.)

149,620 (.988 × 846.85 + 350.3 − 95.1) = 163,370,078 B. T. U.

(D) See (*m*) Boiler Test Data.

(E) Total heat in one pound of wet steam as made by the boiler $= (xr + q) = (.988 \times 846.85 + 350.3) = 1{,}187$.

Returns entered boiler at 369.7° F.

Heat of liquid at this temperature = 341.9.

Heat put into this is equal to 19,587 (1,187 — 341.9) = 16,552,974 B. T. U.

(F) See (*n*) Boiler Test Data.

(G) Calculated same as (E).

$$136\ (1{,}187 - 341.9) = 114{,}934 \text{ B. T. U.}$$

(H) Found by taking the sum of (C), (E), and (G).

(I) See (*g*) Boiler Test Data.

(I_a) By deducting 200 pounds from (I).

(J) Is equal to (H) ÷ (I).

(J_a) Is equal to (H) ÷ (I_a).

(K) Found by dividing (J) by 965.8, the latent heat of steam at 212° or at atmospheric pressure.

(K_a) (J_a) ÷ 965.8.

(L) Estimated from the excess over the previous rate of firing.

(M) (I) ÷ 24.93 × 68.75.

Calculation of Engine Results and Duty.

(3) The different mean effective pressures (38, p. 88) were calculated by multiplying the total area of all the cards from one end by the spring and dividing by the total length.

The diameters of the cylinders and rods are:

High.		Intermediate.		Low.	
Piston.	Rod.	Piston.	Rod.	Piston.	Rod.
13.7	3.125	24.375	4	39	4

Stroke, 72″.

$$\text{H. P. of high pressure H. E.} = \frac{147.41 \times 59.58 \times 50.59 \times 6}{33{,}000} = 80.78.$$

$$\text{H. P. of high pressure C. E.} = \frac{139.74 \times 54.52 \times 50.59 \times 6}{33{,}000} = 70.08.$$

$$\text{H. P. of intermediate H. E.} = \frac{466.63 \times 22.61 \times 50.59 \times 6}{33{,}000} = 97.05.$$

$$\text{H. P. of intermediate C. E.} = \frac{454.06 \times 21.33 \times 50.59 \times 6}{33{,}000} = 89.09.$$

$$\text{H. P. of low H. E.} = \frac{1{,}194.5 \times 10.66 \times 50.59 \times 6}{33{,}000} = 117.12.$$

$$\text{H. P. of low C. E.} = \frac{1{,}181.93 \times 11.18 \times 50.59 \times 6}{33{,}000} = 121.54.$$

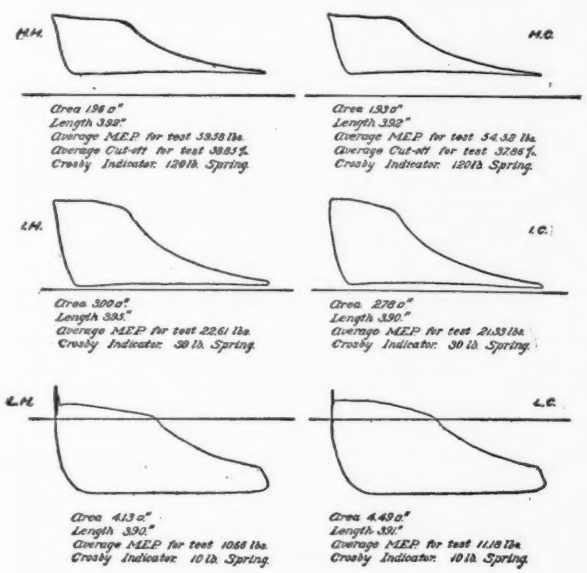


FIG. 2.

INDICATOR CARDS. CHESTNUT HILL PUMPING ENGINE. STEAM CYLINDERS.

(4) The water plungers were all 17.5″ diameter, 48″ stroke, with 3.5″ diameter piston rod. The mean effective pressures as calculated from the water cards are given in (39, p. 88). Cards marked *S* are from the end of the pump nearest the steam cylinders; those marked *P* from the opposite end.

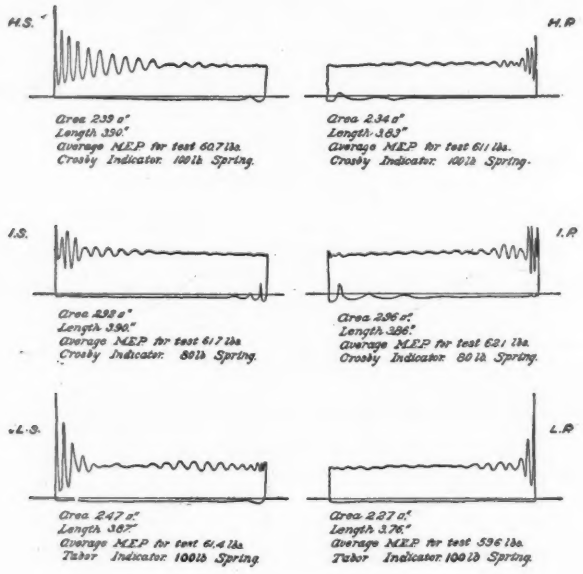


FIG. 3.

INDICATOR CARDS. CHESTNUT HILL PUMPING ENGINE. WATER CYLINDERS.

Pump opposite High.

$$\text{H. P. of S. E.} = \frac{230.90 \times 60.7 \times 50.59 \times 4}{33{,}000} = 85.95.$$

$$\text{H. P. of P. E.} = \frac{240.52 \times 61.1 \times 50.59 \times 4}{33{,}000} = 90.12.$$

Pump opposite Int.

$$\text{H. P. of S. E.} = \frac{230.90 \times 61.7 \times 50.59 \times 4}{33{,}000} = 87.36.$$

$$\text{H. P. of P. E.} = \frac{240.52 \times 62.1 \times 50.59 \times 4}{33{,}000} = 91.59.$$

Pump opposite Low.

$$\text{H. P. of S. E.} = \frac{230.90 \times 61.4 \times 50.59 \times 4}{33{,}000} = 86.94.$$

$$\text{H. P. of P. E.} = \frac{240.52 \times 59.6 \times 50.59 \times 4}{33{,}000} = 87.90.$$

(6) This is the sum of 2, 4, 5, and 13 of Engine Test Data.

(7) Sum of (5) and (6) of Engine Test Results.

(8) This is the total steam for engine cylinders and jackets for one hour divided by the total H. P. of steam cylinders.

$$\frac{155{,}043}{24 \times 575.66} = 11.22.$$

(9) The steam required for the plant for twenty-four hours, excepting that used by the high pressure jackets, is found by deducting the sum of items 7, 8, 9, 10, and 11 from item 6.

(10) $146{,}226\ (.988 \times 846.85 + 350.3 - 95.1)$
$= 159{,}664{,}169$ B. T. U.

(11) Estimated as previously explained.

(13) $19{,}370\ (1{,}187 - 341.9) = 16{,}369{,}587$ B. T. U.

(14) Sum of (10) and (13).

(15) See Boiler Test Results (J).

(16) This is found by dividing (14) by (15).

(16_a) (14) $\div$ (J_a).

(17) and (19) The water over the weir (Fig. 4, p. 115) was calculated first by the formula:

$$\text{Cu. ft. per second} = 3.33\ l\ h^{\frac{3}{2}}.$$

$l = 10.0026$ ft. $h = .9798$ ft., the observed height on weir.

A correction was then made for the velocity of approach. The area of a cross section of the weir at this depth was 60.3354 sq. ft.

The quantity in cubic feet per twenty-four hours was then calculated from this formula:

$$3.33\ l \left[\left(h + \frac{v^2}{2g}\right)^{\frac{3}{2}} - \left(\frac{v^2}{2g}\right)^{\frac{3}{2}}\right] 24 \times 60 \times 60 = 2{,}809{,}370 \text{ cu. ft.}$$

$$\frac{2{,}809{,}370 \times 1{,}728}{231} = 21{,}016{,}000 \text{ gallons.}$$

(20) $3 \times \frac{(230.9 + 240.52)}{144} \times 4 \times 50.59 \times 60 \times 24 = 2{,}861{,}640$ cu. ft. displacement of pump plungers.

(21) See items 33, 34, 35, 36, 37.

$$145.87 - 122.65 = 23.22 \text{ ft.}$$
$$100.88 \times .4891 \times 2.307 = 113.83.$$
$$113.83 + 23.22 = 137.05 \text{ ft. total head.}$$

The specific gravity of the mercury used was determined immediately after the test was finished. From this items 36 and 37 were calculated.

(22) This is the product of (17), (18), and (21).

(23) From items (22) and (16)

$$\frac{24{,}025{,}507{,}490 \times 100}{16{,}465} = 145{,}919{,}000.$$

(23_a) From items (22) and (16_a).

(24) (24_a) and (29).

The B. T. U. required by the engine for twenty-four hours was calculated in this way:

The total heat of the steam supplied to the cylinders above the heat of the condensed steam, plus the heat lost by the jacket steam in the high, intermediate, first and second reheater jackets, plus also the heat lost in the low pressure cylinder jackets, and in the drips from the working sides of the first and second reheaters above the heat of the liquid entering the economizer.

$$\begin{aligned} 128{,}471 \ (1{,}187.0 - 57.3) &= 145{,}133{,}688 \\ 19{,}370 \times 845.1 &= 16{,}369{,}587 \\ 7{,}202 \times 1{,}091.9 &= 7{,}863{,}864 \\ &\overline{\qquad\qquad} \\ &169{,}367{,}139 \end{aligned}$$

$$\frac{169{,}367{,}139}{24 \times 60 \times 575.66} = 204.3 \text{ B. T. U. per H. P. per minute.}$$

204.3 × 60 equals the B. T. U. per H. P. per hour. Divide this by the B. T. U. taken up from 1 pound of coal.

$$\frac{204.3 \times 60}{10{,}691.7} = 1.146. \qquad \frac{204.3 \times 60}{10{,}820.2} = 1.113.$$

(25) and (25_a) From (23) and (23_a) get the foot-pounds of water work done per pound of coal.

$$\frac{33{,}000 \times 60}{1{,}459{,}186} = 1.36. \qquad \frac{33{,}000 \times 60}{1{,}476{,}766} = 1.34.$$

(26) From (20) and (17)

$$\frac{2{,}861{,}640 - 2{,}809{,}370}{2{,}861{,}640} = 1.83 \text{ per cent. slip.}$$

(27) $\frac{137.05}{2.307} = 59.406$, the mean effective pressure due to head.

The H. P. of pumps calculated on this M. E. P. is

$$\frac{3 \times (240.52 + 230.9) \times 50.59 \times 59.406 \times 4}{33{,}000} = 515.19.$$

$$\frac{575.66 - 515.19}{575.66} = 10.54 \text{ per cent.}$$

(28) $100 - 10.54 = 89.46$.

(30) $\frac{33{,}000}{778} = 42.42$ B. T. U. required for one H. P.

$\frac{42.42}{204.3} = 20.76$ per cent. thermal efficiency.

(31) This is equal to the difference of absolute temperatures divided by the higher temperature:

$$\frac{(377.7 + 460.7) - (113.5 + 460.7)}{(377.7 + 460.7)} = 31.51 \text{ per cent.}$$

(32) $\frac{20.76}{31.51} = 65.9$.

(33) Duty (foot-pounds per 1,000,000 B. T. U.)

The total B. T. U. required by engine in twenty-four hours is (see calculation of (29)) 169,367,139.

$$\frac{24{,}025{,}507{,}490}{169{,}367{,}139} \times 1{,}000{,}000 = 141{,}855{,}000.$$

(34) The foot-pounds of work done per revolution as figured from the 24-hour test is equal to

$$\frac{24,025,507,490.}{72,843}$$

The total work done from the time of opening the throttle, or for 73,516 revolutions, is 24,247,503,172 foot-pounds.

The total coal burned for the entire test was 16,839 pounds.

$$\frac{24,247,503,172}{168.39} = 143,996,000.$$

$$(34_a) \qquad \frac{24,247,503,172}{166.39} = 145,727,000.$$

$$(35_a) \quad \frac{3\,(230.9 + 240.52)}{144} \times 4 \times 72,843 \times 137.05 \times 62.4 =$$

24,472,490,693 foot-pounds of work done in 24-hour test, figuring from displacements of water plungers.

$$\frac{24,472,490,693}{16,269} = 150,424,000 \text{ duty.}$$

$$(36_a) \quad \frac{3\,(230.9 + 240.52)}{144} \times 4 \times 73,516 \times 137.05 \times 62.4 =$$

24,698,595,419 foot-pounds.

$$\frac{24,698,595,419}{16,639} = 148,437,900 \text{ duty.}$$

BOILER TEST DATA.

Kind of coal, George's Creek, Cumberland.
Grate surface = 68.75 sq. ft.
Heating surface = 2,849.0 sq. ft.

Weights.

a	Weight of wood fired at starting	401.5 lbs.
b	Coal equivalent of wood	161.0 "
c	Weight of coal fired in 24.93 hours	16,734 "
d	Weight of coal fired, including coal equivalent of wood	16,895 "
e	Weight of mixture drawn from grate at end of test	224.5 "
f	Weight of good coal in this mixture	56.0 "
g	Weight of coal burned in 24.93 hours	16,839 "
h	Weight of ash, etc., from ash-pit	1,063.5 "
i	Weight of good coal in this	63 "
j	Weight of water weighed in barrels in boiler room	151,060 "
k	Weight of leakage from feed pump	1,440 "
l	Weight of water put into boiler by feed pump	149,620 "
m	Weight of water returned to boiler from high pressure jackets, engine running, as determined by separate test made immediately afterwards	19,587 "
n	Weight of water returned to boiler from high pressure jackets between time of starting boiler and of opening throttle (determined by separate test)	136 "
o	Weight of steam used by economizer scraper engine	722 "

Temperature.

	Average temperature of room	23.3° C.
	Temperature of outside air	4.2° C.
p	Temperature of gases leaving boiler and entering economizer	502° F.
q	Temperature of gases leaving economizer	233° F.
r	Temperature of feed water entering economizer	127° F.
s	Temperature of feed water leaving economizer	198.3° F.
t	Temperature of high pressure jacket returns entering boiler	369.6° F.
u	Temperature of high pressure jacket returns leaving engine	370.6° F.

Pressure.

v	Average pressure at throttle	175.7 lbs.
	Average draught pressure in inches of water	.375 in.
w	Barometer in inches of mercury, 30.25"	14.85 lbs.
x	Pressure at starting boiler test	86 "
y	Pressure at stopping boiler test	86.5 "

Time.

Time starting boiler test	8.30 A.M., May 1.
Time ending test	9.26 " "
Duration of test	24.93 hours.
Time starting engine	9.09 A.M., May 2.
Time stopping engine	9.26 " "

Detail of Heating Surface in Boiler.

Fire-boxes	288 sq. ft.	Area of grate	68.75 sq. ft.
Flues	83 "	Area of inside cross section of tubes	8.49 "
Combustion chamber	102 "	Volume of water 6" above crown sheet	617 cu. ft.
Tubes (fire side)	2,343 "	Volume of steam space, water 6" above crown sheet	416 "
Back tube sheet	33 "		
Total heating surface	2,849 sq. ft.		

ENGINE TEST DATA.

Weights.

1.	Steam through cylinders (24 hours)	128,471 lbs.
2.	Weight of drip, L. P. jacket (24 hours)	3,656 "
3.	Weight of drip, separator	585 "
4.	Weight of drip, working side, 1st receiver (24 hours)	3,118 "
5.	Weight of drip, working side, 2d receiver (24 hours)	428 "
6.	Weight of water weighed for boiler in boiler room barrels (24.93 hours)	151,060 "
7.	Make-up before starting engine test	997 "
8.	Water from engine room before starting engine test	454 "
9.	Water from engine room after ending engine test	663 "
10.	Leakage at feed pump (24 hours)	1,440 "
11.	Steam used by calorimeter	1,280 "
12.	Steam required by plant for 24 hours, except for H. P. jackets	146,226 "
13.	Weight of returns from high intermediate 1st receiver and 2d receiver jackets (24 hours)	19,370 "

Temperatures.

14.	Average temperature of engine room	23.3° C.
15.	Average temperature condensed steam leaving air pump	89.3° F.
16.	Average temperature cold condensing water	51.9° F.
17.	Average temperature hot condensing water	85.2° F.
18.	Average temperature hot well water	140.7° F.
19.	Average temperature feed water entering economizer	127.0° F.
20.	Average temperature feed water leaving economizer	198.3° F.
21.	Average temperature jacket returns entering boiler	369.6° F.

Pressures.

22.	Barometer	14.85 lbs.
23.	Pressure at throttle	175.70 "
24.	Vacuum at condenser in Ins. of Hg.	27.25
25.	Pressure in 1st receiver	46.5 lbs.
26.	Pressure in 2d receiver	2.4 "
27.	Pressure in L. P. jackets	99.6 "
28.	Pressure in H. P. jackets	175.7 "

Water.

29.	Temperature of water	52.6° F.
30.	Average height of water on weir (24 hours test)	.9798 ft.
31.	Width of weir water on weir	100,026 "
32.	Area of cross section of water in weir (24 hours test)	603,354 sq. ft.
33.	Reading suction float (feet above marsh level)	122.65 ft.
34.	Reading level in air chamber (above same level)	145.87 "
35.	Discharge pressure in Ins. of Hg.	100.88
36.	Pressure of 1 inch of Hg. 23.3° C.	.4891 lbs.
37.	Feet of water to 1 pound pressure	2.307 ft.

Steam Cards.

		H		I		L	
		H	C	H	C	H	C
38.	M. E. P.	59.58	54.52	22.61	21.33	10.66	11.18.

Water Cards.

		H		I		L	
		S	P	S	P	S	P
39.	M. E. P.	60.7	61.1	61.7	62.1	61.4	59.6.
40.	Total revolutions (24 hours)						72,843
41.	Revolutions per minute						50.59

BOILER TEST RESULTS.

(A)	Quality of steam as obtained by calorimeter at throttle of engine	.988
(B)	Total feed water put into boiler in 24.93 hours	149,620
(C)	B. T. U. put into same	163,370,078
(D)	Total return from jackets while engine was running	19,587
(E)	B. T. U. put into same	16,552,974
(F)	Total returns from jackets while engine was still	136
(G)	B. T. U. put into same	114,934
(H)	Total B. T. U. taken up from coal by water in the boiler	180,037,986
(I)	Total coal burned	16,839
(I_a)	Coal burned, allowing for 200 pounds due to dropping grate bars	16,639
(J)	B. T. U. taken up by water per pound of coal burned	10,631.7
(J_a)	(J) Allowing for 200 pounds extra coal	10,820.2
(K)	Equivalent evaporation per pound of coal from and at 212° F.	11.07
(K_a)	(K) Allowing for 200 pounds extra coal	11.20
(L)	Probable excess of coal fired due to dropping of grate bars	200
(M)	Coal per square foot of grate per hour	9.8

FLUE GAS ANALYSIS. (Average for each hour.)

	CO_2	O	CO		CO_2	O	CO
10.35–11.00	12.3	6.1	0	10.00–11.00	9.5	10.5	0
11.00–12.00	12.7	4.8	0	11.00–12.00	9.4	10.3	0.1
12.00– 1.00	11.7	5.4	0.4	12.00– 1.00	10.5	6.1	0
1.00– 2.00	12.4	5.1	0.1	1.00– 2.00	6.0	8.2	0.1
2.00– 3.00	13.1	4.4	0	2.00– 3.00	9.6	8.4	0.1
3.00– 4.00	12.3	3.8	0.3	3.00– 4.00	6.0	10.5	0.2
4.00– 5.00	11.9	5.3	0.3	4.00– 5.00	2.8	7.7	0.1
5.00– 6.00	14.5	3.8	0.1	5.00– 6.00	5.3	10.4	0
6.00– 7.00	11.7	6.6	0.3	6.00– 7.00	3.3	11.9	0.1
7.00– 8.00	8.7	9.8	0.3	7.00– 8.00	3.8	11.9	0.5
8.00– 9.00	12.5	6.5	0.2	8.00– 9.00	5.5	11.5	0
9.00–10.00	11.9	4.2	0.2				

ENGINE TEST RESULTS.

(1)	Total revolutions in 24 hours				72,843
(2)	Revolutions per minute				50.59
			H. E.	C. E.	
(3)	Total H. P. of H steam cylinder	80.78	+ 70.08		150.86
	" " I steam cylinder	97.05	89.09		186.14
	" " L steam cylinder	117.12	121.54		238.66
	Total				575.66
		B.	S.		
(4)	Total H. P. of pump opposite H cylinder	90.12	85.95		176.07
	" " " I cylinder	91.59	87.36		178.95
	" " " L cylinder	87.90	86.94		174.84
	Total				529.86
(5)	Steam through cylinders in 24 hours				128,471 lbs.
(6)	Total steam through H, I, and L jackets in 24 hours, and drips from working side and jackets of reheaters				26,572 "
(7)	Total steam for engine and jackets				155,043 "
(8)	Steam per I. H. P. for steam cylinders per hour				11.22 "
(9)	Steam required by plant for 24 hours, excepting steam used by high jackets				146,226 "
(10)	B. T. U. required for the above, 146,226 ($xr + q - q$) entering economizer				159,664,169
(11)	Jacket returns to boiler in 24 hours				19,370 lbs.
(12)	Temperature of returns entering boiler				369.6° F.
(13)	B. T. U. required for above ($xr + q - q$ 369.6), 19,370				16,369,587
(14)	Total B. T. U. required by plant in 24 hours				176,033,756
(15)	B. T. U. taken up from 1 pound of coal				10,691.7
(16)	Coal required for 24 hours				16,465 lbs.
(16_a)	(16) Allowing for 200 pounds extra coal				16,269 "
(17)	Cubic feet of water over weir in 24 hours				2,809,370
(18)	Weight of 1 cubic foot of water at 52.6° F				62.4 lbs.
(19)	Capacity of pump in gallons per 24 hours at speed of 50.59 revolutions per minute (calculated from weir)				21,016,000
(20)	Displacement of pump plungers in cubic feet in 24 hours				2,861,640
(21)	Resistance overcome expressed in feet of water				137.05
(22)	Foot-pounds of water work done in 24 hours				24,025,507,490
(23)	Duty (foot-pounds of water work done for 100 pounds coal)				145,919,000
(23_a)	Duty calculated, allowing for extra coal burned due to dropping grate bars				147,677,000
(24)	Coal per steam horse power per hour (engine)				1.146 lbs.
(24_a)	(24) Allowing for 200 pounds extra coal				1.113 "
(25)	Coal per H. P. of actual water work done				1.36 "
(25_a)	Coal per H. P. of actual water work done, allowing for 200 pounds extra coal				1.34 "
(26)	Slip				1.83 per cent.
(27)	Friction of engine, pump valves, and piping up to delivery (calculating H. P. of water by taking for M. E. P. (515.19) the total head in pounds)				10.54 per cent.
(28)	Efficiency of mechanism				89.46 per cent.
(29)	B. T. U. per H. P. per minute				204.3
(30)	Thermal efficiency of engine				20.76 per cent.
(31)	Efficiency of a Carnot engine working between 175.7 pounds gauge and 27.25" vacuum,				31.51 per cent.
(32)	Per cent. efficiency of Carnot engine				65.9 per cent.
(33)	Duty (foot-pounds per 1,000,000 B. T. U.)				141,855,000
(34)	Duty calculated by taking total coal used in 24.93 hours, and the total work done by engine from time of opening throttle to time of stopping				143,996,000
(34_a)	(34) Allowing for 200 pounds excess of coal				145,727,000
(35_a)	Duty 24-hour test (figuring from displacement of water plungers, and allowing for 200 pounds excess of coal)				150,424,000
(36_a)	Duty calculated from the total displacement of water plungers from the time of opening the throttle and taking the total coal burned during the boiler test with 200 pounds allowance				148,438,000

NOTE. —(35_a) and (36_a) are given so that these results may be compared with those from other pumping engines where no weir measurements were taken and the duty figured from displacements.

STEAM CARDS. HIGH PRESSURE. Nos. 6 and 7.

Scale 120. Crosby Indicators. (Late pattern).

Time.	Area. H. E.	Length. H. E.	Per cent. cut off. H. E.	Area. C. E.	Length. C. E.	Per cent. cut off. C. E.	Time.	Area. H. E.	Length. H. E.	Per cent. cut off. H. E.	Area. C. E.	Length. C. E.	Per cent. cut off. C. E.
9.15	1.83	3.94	37.5	1.73	3.97	40.7	10.15	1.97	3.95	38.5	1.88	3.88	37.0
9.30	1.89	3.92	38.5	1.81	3.88	37.7	10.30	1.96	3.94	40.0	1.91	3.93	37.0
9.45	1.94	3.96	38.3	1.90	3.96	36.0	10.45	1.95	3.91	40.0	1.87	3.90	37.5
10.00	1.93	3.91	37.2	1.88	3.92	36.0	11.00	1.99	3.93	37.0	1.91	3.90	37.0
10.15	1.94	3.90	37.5	1.84	3.91	37.7	11.15	1.95	3.93	39.0	1.89	3.95	37.5
10.30	1.96	3.91	38.2	1.88	3.92	36.75	11.30	1.95	3.95	37.5	1.90	3.93	38.0
10.45	1.96	3.93	39.0	1.89	3.95	37.25	11.45	1.97	3.93	38.0	1.92	3.90	37.0
11.00	1.96	3.92	40.3	1.83	3.92	37.5	12.00	2.00	3.90	39.5	1.88	3.87	37.6
11.15	1.96	3.92	39.3	1.84	3.92	37.0	12.15	1.96	3.93	40.5	1.89	3.94	37.5
11.30	1.97	3.92	39.0	1.85	3.92	37.5	12.30	1.94	3.93	39.5	1.88	3.86	37.0
11.45	1.95	3.93	40.5	1.90	3.92	38	12.45	1.99	3.92	40.0	1.89	3.92	37.5
12.00	1.95	3.92	38.2	1.89	3.93	38	1.00	1.97	3.94	40.0	1.91	3.96	38.0
12.15	1.96	3.90	38 0	1.91	3 90	39 5	1.15	1.95	3.94	37.0	1.92	3.90	36.0
12.30	1.92	3.93	39 0	1.93	3.95	38.25	1.30	1.97	3.94	38.5	1.92	3.91	38.0
12.45	1.98	3.93	39.0	1.85	3.96	37.0	1.45	1.93	3.93	40.5	1.90	3.92	40.5
1.00	1.98	3.88	39.2	1.90	3.93	37.7	2.00	1.94	3.92	38.25	1.90	3.94	37.5
1.15	1.99	3.93	38.0	1.89	3.91	37.7	2.15	1.98	3.89	35 0	1.91	3.95	38.0
1.30	1.98	3.94	38.5	1.89	3 90	37.0	2.30	1.99	3.93	38.0	1.92	3.93	37.5
1.45	1.97	3.89	39.2	1.89	3.92	36.0	2.45	1.95	3.92	39.5	1.91	3.94	37.0
2.00	1.98	3.94	39 2	1.88	3.97	38.2	3.00	1.98	3.91	37.5	1 91	3.91	37.0
2.15	1.95	3.93	38.5	1.91	3.92	37.5	3.15	1.98	3.93	39.0	1.92	3.94	37.5
2.30	1.97	3.92	38.5	1.87	3.93	38.2	3.30	1.94	3.94	37.0	1.92	3.91	38.0
2.45	1.97	3.94	39.0	1.94	3.93	37.0	3.45	1.99	3.93	39.0	1.92	3.90	37.0
3.00	1.94	3.91	38.5	1.90	3.92	38.25	4.00	1.97	3.92	38.0	1.90	3.92	37.0
3.15	1.98	3.90	38.5	1.89	3 94	37.5	4.15	1.97	3.91	38.0	1.91	3.91	37.0
3.30	1.96	3.88	38.5	1.93	3.94	37.5	4.30	1.95	3.92	38.5	1.91	3.91	....
3.45	1.95	3.90	38.0	1.95	3.94	38.0	4.45	1.97	3.93	37.5	1.92	3.94	38.0
4.00	1.96	3.90	37.75	1.92	3.92	37.75	5.00	1.98	3.92	40.0	1.92	3.96	38.0
4.15	1.98	3.90	38 5	1.82	3.91	37.0	5.15	1.96	3.93	38 5	1.91	3 91	38.5
4.30	1.97	3 97	37.5	1.91	3.93	37.5	5.30	1.54	3.92	54.5	1.54	3.97	54.0
4.45	2.01	3.92	38 0	1.91	3 91	36.5	5.45	1.68	3.93	38.0	1.70	3.97	47.0
5.00	1.98	3.88	38.0	1.92	3.90	36.0	6.00	1.96	3.97	39.0	1.94	3.90	37.0
5.15	1.96	3.92	39.0	1.93	3.92	38.0	6.15	1.97	3.91	39.0	1.95	3.94	38.5
5.30	1.97	3.93	38.8	1.90	3.92	36.5	6.30	1.96	3.92	39.0	1.95	3.95	38.5
5.45	1.97	3.91	38 8	1.90	3.92	31.0	6.45	1.95	3.92	34.5	1.92	3.92	36.5
6.00	1.97	3.90	35.0	1 89	3.94	37.5	7.00	1.95	3.91	37.0	1.94	3.93	36.5
6.15	2.00	3.94	39.0	1.91	3.90	32.0	7.15	1.96	3.92	38.0	1.91	3.90	37.0
6.30	1.95	3.90	36.5	1.90	3.94	37.0.	7.30	2.00	3.90	40.5	1.95	3.96	37.0
6.45	2.00	3.92	39.3	1.92	3.94	37.0	7.45	2.00	3.93	39 0	1.95	3.94	37.0
7.00	1.94	3.92	38.0	1.88	3.90	37.0	8.00	1.98	3.96	38.0	1.94	3.94	38.0
7.15	1.98	3.94	39.0	1.90	3.92	38.0	8.15	1.98	3.91	40.0	1.95	3.94	39.0
7.30	1 91	3.88	36.5	1.91	3.92	37.0	8.30	1.99	3.91	38.0	1.95	3.95	36.5
7.45	1.99	3.92	39.0	1.88	3.86	37.5	8.45	1.97	3.93	38.5	1.95	3.93	38.0
8.00	2.03	3.93	39.5	1.92	3.92	37.5	9.00	1.78	3.93	45.0	1.74	3.91	45.0
8.15	1.95	3.86	38.0	1.87	3.88	36.5	9.15	1.09	3.90	73.5	1.10	3.79	73.0
8.30	2.03	3.88	39.0	1.87	3 90	36.5							
8 45	1.95	3.92	38.5	1.88	3.89	38 5							
9.00	1.97	3.89	38.0	1.89	3.92	38.0	Total,	188.80	380.26	3,768.70	172.83	380.39	3,634.85
9.15	2.00	3.91	18.0	1.90	3.92	36.5							
9.30	1.95	3.92	37.0	1.90	3.91	37.0							
9.45	1.95	3.92	38.0	1.89	3.89	39.0	Av. =			38.85%		Av. =	37.86%
10.00	1.95	3.94	39.5	1.91	3.95	37.8							

STEAM CARDS. INTERMEDIATE. Nos. 8 and 9.

Scale 30. Crosby Indicators.

Time.	Area. H. E.	Length. H. E.	Area. C. E.	Length. C. E.	Time.	Area. H. E.	Length. H. E.	Area. C. E.	Length. C. E.
9.15	2.98	3.88	2.87	3.98	9.45	2.98	3.93	2.82	3.99
9.30	2.98	3.90	2.80	3.98	10.00	2.85	3.94	2.80	3.96
9.45	2.96	3.94	2.82	3.96	10.15	2.91	3.92	2.80	3.99
10.00	2.91	3.81	2.83	3.98	10.30	2.96	3.95	2.79	3.99
10.15	3.03	3.88	2.86	3.96	10.45	2.96	3.95	2.77	3.98
10.30	3.01	3.91	2 80	3.98	11.00	3.02	3.92	2.82	4.00
10.45	3.00	3.91	2.80	3.98	11.15	3.04	3.91	2.81	3.96
11.00	2.99	3.90	2.80	3.97	11 30	3.03	3.92	2.82	3.97
11.15	2.96	3.90	2.80	3.98	11.45	2.98	3.95	2.82	3.97
11.30	3.02	3.92	2.77	3.99	12.00	2.99	3.94	2.78	3.97
11.45	3.01	3.90	2.74	3.98	12.15	3.00	3.95	2.82	3.96
12.00	2.98	3.90	2.77	3.88	12.30	2.94	3.98	2.86	3.98
12.15	2.95	3.92	2.72	3.88	12.45	2.98	3.94	2.80	3.98
12.30	2.97	3.90	2.78	3.96	1.00	2.97	3.92	2.84	3.98
12.45	3.00	3.91	2.80	3.97	1.15	2.80	3.94	2.75	3.98
1.00	2.95	3.94	2.78	3.98	1.30	2.98	3.90	2.78	3.97
1.15	2.98	3.93	2.78	3.98	1.45	3 00	3.94	2.80	3.99
1.30	2.91	3.92	2.76	3.99	2.00	3.02	3.82	2.82	3.98
1.45	2.90	3.95	2.78	3.98	2.15	2.97	3.92	2.80	3.99
2.00	2.93	3.95	2.80	3.98	2.30	3.00	3.93	2.86	4.00
2.15	2.91	3.96	2.81	3.99	2.45	3.01	3.94	2.82	3.97
2.30	2.93	3.95	2.79	3.97	3.00	3.00	3.94	2.74	3.98
2.45	2.93	3.94	2.80	4.00	3.15	3.00	3.95	2.82	4.00
3.00	2.97	3.97	2.80	3.97	3.30	2.95	3.92	2.83	3.96
3.15	2.93	3.95	2.79	3.98	3.45	3.00	3.94	2.88	3.98
3.30	2.93	3.97	2 80	3.98	4.00	2.99	3.92	2.84	3.96
3.45	2.97	3.94	2.80	3.99	4.15	2.98	3.93	2.81	3.97
4.00	2 97	3.96	2.80	3.98	4.30	2.96	3.94	2.86	3.96
4.15	2.96	3.94	2.81	3.95	4.45	2.93	3.94	2.79	3.96
4.30	2 95	3.97	2.81	3.98	5.00	2.94	3.95	2.88	3.98
4.45	3.04	3.95	2.79	3.97	5.15	3.00	3.94	2.80	3.95
5.00	3.00	3.95	2.81	3.96	5.30	3.24	3.94	3.06	3.99
5.15	3.00	3.95	2.78	3.90	5.45	3.17	3.95	3.08	3.95
5.30	2.97	3.95	2.84	3.98	6.00	3.06	3.95	2.90	3.95
5.45	2.97	3.96	2.83	3.97	6.15	2.95	3.96	2.88	3.98
6.00	2.95	3.95	2.81	3.97	6.30	2.95	3.94	2.90	3.98
6.15	2.95	3.98	2.81	3.98	6.45	2.85	3.95	2.75	3.99
6.30	2.90	3.94	2.81	3.97	7.00	2.82	3.95	2.68	4.00
6.45	2.93	3.93	2.82	3.97	7.15	2.85	3.96	2.75	3.97
7.00	2.93	3.92	2.80	3.98	7.30	2.97	3.96	2.82	4.00
7.15	2.94	3.96	2.83	3.98	7.45	2.95	3.94	2.84	3.98
7.30	2.93	3.93	2.84	3.99	8.00	3.03	3.97	2.94	3.99
7.45	2.97	3.97	2.81	3.96	8.15	2.97	3.96	2.83	3.98
8.00	2.91	3.93	2.81	3.96	8.30	2.94	3.95	2.86	3.97
8.15	2.99	3.92	2.86	3.99	8 45	2.94	3.95	2.90	3.98
8.30	2.96	3.94	2.84	3.98	9.00	3.10	3.95	3.00	3.98
8.45	2.95	3.96	2.80	3.97	9.15	3.54	3.96	3.40	3.99
9.00	2.95	3.95	2.82	3.98					
9.15	2.95	3.97	2.81	3.94					
9.30	2.94	3.93	2.82	3.97	Total,	288.47	381.78	274.03	385.45

STEAM CARDS. LOW PRESSURE. Nos. 10 and 11.

Scale 10. Crosby Indicators.

Time.	Area. H. E.	Length. H. E.	Area. C. E.	Length. C. E.	Time.	Area. H. E.	Length. H. E.	Area. C. E.	Length. C. E.	Time.	Area. H. E.	Length. H. E.	Area. C. E.	Length. C. E.
9.15	4.42	3.90	....	....	5.30	4.14	3.87	4.48	3.90	1.45	4.20	3.94	4.44	3.93
9.30	4.16	3.90	4.28	3.98	5.45	4.16	3.88	4.38	3.91	2.00	4.09	3.90	4.47	3.91
9.45	4.23	3.91	4.26	3.82	6.00	4.14	3.87	4.36	3.92	2.15	4.13	3.90	4.31	3.92
10.00	4.23	3.91	4.25	3.81	6.15	4.17	3.89	4.47	3.92	2.30	4.13	3.90	4.49	3.91
10.15	4.23	3.91	4.20	3.99	6.30	4.15	3.90	4.45	3.92	2.45	4.10	3.90	4.45	3.90
10.30	4.18	3.92	4.15	3.82	6.45	4.22	3.88	4.39	3.98	3.00	4.12	3.90	4.39	3.90
10.45	4.23	3.94	4.25	3.94	7.00	4.20	3.92	4.30	3.90	3.15	4.14	3.87	4.35	3.89
11.00	4.23	3.92	4.23	3.84	7.15	4.16	3.90	4.39	3.94	3.30	4.09	3.90	4.38	3.90
11.15	4.20	3.90	4.23	3.91	7.30	4.17	3.91	4.35	3.92	3.45	4.17	3.90	4.37	3.88
11.30	4.22	3.90	4.22	3.83	7.45	4.14	3.87	4.36	3.90	4.00	4.12	3.89	4.31	3.86
11.45	4.17	3.91	4.22	3.91	8.00	4.18	3.90	4.48	3.92	4.15	4.08	3.89	4.39	3.92
12.00	4.46	4.02	4.23	3.90	8.15	4.15	3.90	4.39	3.93	4.30	4.13	3.90	4.29	3.88
12.15	4.21	3.90	4.39	3.97	8.30	4.21	3.92	4.39	3.92	4.45	4.12	3.90	4.35	3.95
12.30	4.13	3.88	4.40	4.04	8.45	4.16	3.90	4.34	3.95	5.00	4.12	3.91	4.36	3.93
12.45	4.14	3.91	4.38	3.98	9.00	4.16	3.88	4.39	3.91	5.15	4.08	3.89	4.28	3.86
1.00	4.15	3.88	4.39	4.01	9.15	4.14	3.87	4.40	3.91	5.30	4.38	3.89	4.51	3.87
1.15	4.16	3.88	4.41	3.98	9.30	4.14	3.89	4.38	3.95	5.45	4.30	3.88	4.56	3.93
1.30	4.16	3.89	4.42	3.96	9.45	4.22	3.88	4.39	3.91	6.00	4.11	3.90	4.39	4.01
1.45	4.08	3.87	4.43	3.95	10.00	4.12	3.99	4.41	3.92	6.15	4.08	3.89	4.35	3.90
2.00	4.18	3.92	4.45	3.92	10.15	4.12	3.85	4.47	3.95	6.30	4.06	3.89	4.28	3.90
2.15	4.14	3.90	4.44	3.90	10.30	4.10	3.89	4.38	3.92	6.45	3.96	3.88	4.25	3.93
2.30	4.22	3.95	4.41	3.99	10.45	4.16	3.91	4.44	3.92	7.00	3.95	3.90	4.20	3.98
2.45	4.16	3.90	4.40	3.93	11.00	4.16	3.88	4.40	3.91	7.15	3.96	3.90	4.27	3.97
3.00	4.16	3.89	4.45	3.91	11.15	4.16	3.90	4.53	3.94	7.30	4.15	3.89	4.33	3.91
3.15	4.22	3.92	4.40	3.90	11.30	4.15	3.89	4.48	3.95	7.45	4.12	3.90	4.35	3.90
3.30	4.15	3.89	4.42	3.91	11.45	4.17	3.88	4.40	3.90	8.00	4.03	3.88	4.33	3.92
3.45	4.16	3.88	4.43	3.94	12.00	4.18	3.90	4.46	3.94	8.15	4.11	3.94	4.35	3.90
4.00	4.14	3.88	4.40	3.90	12.15	4.18	3.89	4.39	3.92	8.30	4.03	3.88	4.36	3.94
4.15	4.14	3.90	4.39	3.92	12.30	4.17	3.90	4.45	3.90	8.45	4.02	3.90	4.33	3.91
4.30	4.14	3.92	4.41	3.91	12.45	4.16	3.90	4.51	3.95	9.00	4.16	3.87	4.49	3.95
4.45	4.13	3.88	4.42	3.94	1.00	4.18	3.90	4.45	3.94	9.15	4.71	3.86	4.95	3.97
5.00	4.05	3.86	4.39	3.90	1.15	4.07	3.90	4.35	3.90					
5.15	4.06	3.87	4.41	3.93	1.30	4.16	3.92	4.42	3.95	Totals,	403.24	378.08	420.72	376.49

TEMPERATURES.

Time.	Temperature first receiver. °F.	Temperature second receiver. °F.	H. P. jacket returns at engine. °F.	Time.	Temperature first receiver. °F.	Temperature second receiver. °F.	H. P. jacket returns at engine. °F.	Time.	Reading temperature room. °C.	Time.	Reading temperature room. °C.
9.15	319	305	370	12.15	320	308	372	12.30	24.5	3.00	22.4
10.15	320	309	370	1.15	320	308	372	1.30	24.4	4.00	22.1
11.15	322	296	370	2.15	320	308	373	2.00	24	5.00	21.9
12.15	322	306	372	3.15	319	306	372	3.00	24.8	6.00	22.0
1.15	322	308	370	4.15	319	306	372	4.00	25.4	7.00	22.0
2.15	322	309	370	6.15	319	306	371	5.00	25.0	8.00	21.4
3.15	322	309	370	7.15	319	306	372	6.00	24.1	9.00	23.0
4.15	322	309	370	8.15	319	306	372	7.00	24.2		
5.15	320	308	372	9.15	318	304	371	8.00	24.0		
6.15	320	308	372	....	308	282	334	9.00	23.3	Total,	5,126
7.15	320	308	372					10.00	23.3		
8.15	320	308	372					11.00	23.2	Av.,	23.3°C.
9.15	320	308	372	Total,	7,992	7,647	9,246	12.00	22.8		
10.15	320	308	372					1.00	22.5		
11.15	320	308	372	Av.,	319.7	305.9	370.6	2.00	22.3		

WATER CARDS. Nos. 12 to 17.

Springs 100 and 80. Crosby Indicators on all but L. S. and L. P.

Time.	Area. H. S.	Length. H. S.	Area. H. P.	Length. H. P.	Area. I. S.	Length. I. S.	Area. I. P.	Length. I. P.	Area. L. S.	Length. L. S.	Area. L. P.	Length. L. P.
9.15	....	....	....	....	2.92	3.86	2.97	3.86	2.47	3.87	2.26	3.80
9.30	2.17	3.56	2.20	3.88	2.94	3.87	2.96	3.86	2.38	3.87	2.27	3.76
9.45	2.16	3.59	2.36	3.84	3.00	3.92	2.99	3.88	2.35	3.86	2.26	3.73
10.00	2 39	3.90	2.34	3.83	2.95	3.88	2.94	3.85	2.34	3.87	2.26	3.76
10.15	2.36	3.88	2.34	3.88	3.00	3.88	3.01	3.86	2.37	3.87	2.30	3.74
10.30	2.41	3.90	2.38	3.90	3.02	3.88	2.96	3.86	2.36	3.88	2.24	3.73
10.45	2.30	3.88	2.34	3.88	2.97	3.88	2.97	3.86	2.36	3.87	2.26	3.73
11.00	2.34	3.88	2.34	3.88	3.00	3.90	2.95	3.86	2.38	3.87	2.28	3.73
11.15	2.41	3.88	2.35	3.87	3.01	3.90	3.00	3.86	2.37	3.86	2.26	3.73
11.30	2.36	3.88	2.34	3.88	2.97	3.86	2.97	3 84	2.35	3.87	2.24	3.73
11.45	2.38	3.88	2.37	3.88	3.16	3.87	2.96	3.86	2.39	3.90	2.28	3.73
12.00	2.34	3.88	2.36	3.88	3.03	3.88	3.00	3.87	2.40	3.86	2.29	3.72
12.15	2.41	3.88	2.32	3 86	2.94	3.86	2.99	3.88	2.36	3.87	2.28	3.73
12.30	2.34	3.88	2.36	3.87	2.98	3.89	2.97	3.86	2.38	3.86	2.28	3.73
12.45	2.41	3.88	2.39	3.88	3.02	3.85	3.01	3.86	2.34	3.87	2.29	3.71
1.00	2.41	3.88	2.31	3.88	2.97	3.88	2.94	3.86	2.36	3.86	2.26	3.73
1.15	2.38	3.90	2.34	3.86	3.00	3.88	2.95	3.86	2.36	3.86	2.24	3.73
1.30	2.33	3.90	2.35	3.86	3 05	3.88	2.98	3.88	2.38	3.87	2.26	3.73
1.45	2.39	3.90	2.33	3.82	3.06	3.87	2.96	3.84	2.36	3.86	2.22	3.73
2.00	2.41	3.90	2.37	3.83	3.01	3.86	2.98	3.86	2.36	3.86	2.24	3.73
2.15	2 42	3.90	2.30	3.84	2.99	3.88	3.00	3.86	2.35	3.86	2.26	3.73
2.30	2.39	3.90	2.39	3.84	2.93	3.87	2.92	3.80	2.39	3.87	2.22	3.73
2 45	2.39	3.90	2.34	3.85	2.96	3.88	2.92	3.84	2.37	3.86	2.25	3.73
3.00	2.39	3.90	2.50	3.90	2.98	3.88	3.00	3.86	2.35	3.86	2.28	3.73
3.15	2.41	3.90	2.30	3.84	2.95	3.88	2.98	3.86	2.36	3.86	2.25	3.73
3.30	2.41	3.90	2.38	3.84	3.08	3.88	2.96	3.86	2.37	3.86	2.26	3.73
3.45	2.39	3.90	2.34	3.80	2.97	3.86	2.97	3.86	2.37	3.86	2.28	3.73
4.00	2.41	3.90	2.30	3.84	2.93	3.86	2.98	3 86	2.36	3.87	2.29	3.72
4.15	2.36	3.90	2.33	3.83	2.94	3.86	2.95	3.86	2.35	3.87	2.30	3.74
4.30	2.32	3.89	2.33	3 84	2.96	3.86	2.97	3.88	2.39	3.85	2.20	3.71
4.45	2.38	3.89	2 40	3.82	2.97	3.88	2.98	3.86	2.50	3.84	2.37	3.70
5.00	2.43	3.86	2.34	3.81	2.90	3.84	2.98	3.82	2.29	3.84	2.20	3.70
5.15	2.33	3.86	2.34	3.81	2.99	3.86	2.95	3.84	2.31	3.82	2.36	3.70
5.30	2.39	3.90	2.35	3.82	3.01	3.89	2.93	3.84	2.38	3.86	2.23	3.70
5.45	2.38	3 87	2.34	3.82	2.97	3.88	2.99	3.86	2.35	3.86	2.15	3.70
6.00	2.40	3.87	2.35	3.83	3.04	3.89	2.97	3.82	2.40	3.84	2.27	3.72
6.15	2.34	3.88	2.34	3.82	3.02	3.89	2.89	3.82	2.31	3.86	2.25	3.69
6.30	2.37	3.88	2 32	3.81	3.01	3.87	2.94	3.82	2.33	3.86	2.15	3.64
6.45	2.32	3.87	2.35	3.84	3.02	3.88	2 98	3.82	2.35	3.86	2.30	3.72
7.00	2.38	3.88	2.34	3.83	3.10	3.89	2.99	3.82	2.40	3.86	2.28	3.69
7.15	2 34	3.88	2.31	3.83	2.97	3.90	2.98	3.86	2.30	3.86	2.26	3.68
7.30	2.37	3.88	2.32	3.83	2.96	3.88	2.95	3.82	2.31	3.86	2.19	3.66
7.45	2.36	3.88	2.35	3.84	3.03	3.90	2.98	3.86	2.37	3.86	2.21	3.66
8.00	2.37	3.87	2.30	3.82	3.01	3.87	3.02	3.86	2.40	3.86	2.26	3.67
8.15	2.40	3.86	2.39	3.82	2.99	3.92	2.95	3.84	2.34	3.84	2.20	3.64
8.30	2.36	3.90	2.40	3.83	3.14	3.96	2.94	3.83	2.41	3.86	2.14	3.66
8.45	2.40	3.88	2.35	3.82	2.99	3.86	2.98	3.83	2.30	3.86	2.26	3.66
9.00	2.39	3.89	2.34	3.82	3.00	3.91	2.97	3.83	2.45	3.87	2.24	3.68
9.15	2.32	3.86	2.36	3.82	2.93	3.86	2.98	3.84	2.31	3.84	2.15	3.65
9.30	2.31	3.87	2.35	3.82	3.01	3.84	2.96	3.83	2.40	3.84	2.18	3.66
9.45	2.32	3.87	2.30	3.82	2.99	3.88	2.91	3.83	2.39	3.84	2.18	3.66

WATER CARDS. Nos. 12 to 17. — *Continued.*

Springs 100 and 80. Crosby Indicators on all but L. S. and L. P.

Time.	Area. H. S.	Length. H. S.	Area. H. P.	Length. H. P.	Area. I. S.	Length. I. S.	Area. I. P.	Length. I. P.	Area. L. S.	Length. L. S.	Area. L. P.	Length. L. P.
10.00	2.34	3.86	2.30	3.81	2.92	3.86	2.95	3.83	2.34	3.84	2.18	3.64
10.15	2.32	3.86	2.34	3.82	3.02	3.87	2.96	3.83	2.40	3.86	2.21	3.64
10.30	2.32	3.86	2.35	3.82	3.01	3.89	2.95	3.83	2.34	3.84	2.19	3.65
10.45	2.33	3.86	2.33	3.80	3.00	3.90	2.97	3.84	2.35	3.84	2.10	3.64
11.00	2.32	3.86	2.35	3.80	2.99	3.90	3.01	3.85	2.35	3.88	2.20	3.66
11.15	2.36	3.87	2.35	3.81	2.97	3.88	3.01	3.83	2.44	3.87	2.22	3.65
11.30	2.39	3.90	2.41	3.80	3.06	3.86	3.00	3.84	2.28	3.86	2.19	3.63
11.45	2.37	3.89	2.31	3.80	2.91	3.87	2.98	3.84	2.38	3.86	2.17	3.60
12.00	2.40	3.90	2.38	3.80	3.06	3.88	2.98	3.84	2.31	3.86	2.20	3.64
12.15	2.31	3.88	2.34	3.82	2.96	3.92	3.01	3.85	2.42	3.88	2.07	3.50
12.30	2.39	3.88	2.38	3.80	3.11	3.87	2.99	3.84	2.83	3.84	2.13	3.50
12.45	2.28	3.74	2.38	3.82	3.06	3.87	3.04	3.84	2.50	3.87	2.14	3.50
1.00	2.30	3.88	2.32	3.80	2.95	3.88	3.10	3.84	2.26	3.86	2.02	3.48
1.15	2.31	3.84	2.35	3.80	2.85	3.83	3.00	3.82	2.34	3.88	2.11	3.50
1.30	2.25	3.74	2.33	3.82	2.95	3.92	3.02	3.82	2.41	3.88	2.11	3.48
1.45	2.40	3.92	2.33	3.82	3.03	3.96	2.99	3.84	2.35	3.87	2.02	3.40
2.00	2.38	3.90	2.35	3.80	3.03	3.96	3.03	3.85	2.34	3.88	1.94	3.42
2.15	2.36	3.90	2.33	3.82	3.01	3.93	3.05	3.85	2.32	3.88	2.06	3.42
2.30	2.36	3.92	2.34	3.82	3.08	3.97	3.02	3.84	2.36	3.87	1.93	3.39
2.45	2.37	3.90	2.34	3.82	2.95	3.96	2.99	3.84	2.36	3.88	2.02	3.40
3.00	2.34	3.90	2.35	3.82	3.00	3.94	3.00	3.86	2.37	3.88	2.04	3.36
3.15	2.38	3.88	2.32	3.80	2.98	3.96	3.01	3.82	2.44	3.87	2.15	3.58
3.30	2.39	3.90	2.32	3.80	2.92	3.95	2.99	3.83	2.42	3.87	2.11	3.60
3.45	2.42	3.92	2.33	3.80	2.94	3.97	3.04	3.84	2.40	3.87	2.09	3.60
4.00	2.32	3.92	2.38	3.80	3.01	3.97	3.04	3.82	2.36	3.86	2.18	3.60
4.15	2.34	3.90	2.36	3.80	3.03	3.94	3.04	3.84	2.39	3.88	2.10	3.62
4.30	2.36	3.90	2.40	3.80	2.99	3.96	2.95	3.82	2.36	3.87	2.14	3.54
4.45	2.37	3.92	2.31	3.80	3.00	3.95	2.95	3.85	2.33	3.88	2.15	3.52
5.00	2.34	3.92	2.31	3.80	3.09	3.92	3.01	3.82	2.40	3.87	2.12	3.50
5.15	2.37	3.90	2.32	3.80	2.98	3.97	2.96	3.84	2.40	3.88	2.07	3.52
5.30	2.38	3.90	2.32	3.82	2.98	3.88	2.98	3.82	2.40	3.88	2.11	3.54
5.45	2.39	3.94	2.32	3.78	3.02	3.88	3.01	3.82	2.40	3.87	2.18	3.52
6.00	2.34	3.90	2.35	3.78	2.97	3.86	3.02	3.82	2.40	3.85	2.12	3.52
6.15	2.34	3.90	2.31	3.80	3.01	3.88	2.96	3.84	2.42	3.86	2.18	3.54
6.30	2.37	3.90	2.30	3.80	3.10	3.88	2.98	3.84	2.41	3.86	2.11	3.54
6.45	2.32	3.90	2.30	3.80	2.98	3.92	2.94	3.84	2.32	3.86	2.11	3.50
7.00	2.29	3.90	2.28	3.80	2.85	3.92	2.95	3.82	2.30	3.86	2.06	3.52
7.15	2.30	3.90	2.26	3.80	2.95	3.91	2.94	3.84	2.26	3.86	2.14	3.53
7.30	2.42	3.90	2.31	3.82	3.14	3.94	3.02	3.85	2.40	3.87	2.00	3.44
7.45	2.36	3.90	2.34	3.82	3.14	3.92	3.00	3.84	2.38	3.88	2.06	3.52
8.00	2.34	3.90	2.30	3.80	3.13	3.92	3.00	3.83	2.36	3.86	2.08	3.48
8.15	2.34	3.90	2.30	3.80	3.15	3.94	3.02	3.85	2.43	3.85	2.10	3.40
8.30	2.38	3.90	2.30	3.80	3.14	3.92	3.04	3.84	2.38	3.86	2.12	3.44
8.45	2.35	3.92	2.30	3.80	3.03	3.92	3.02	3.84	2.40	3.87	2.08	3.50
9.00	2.37	3.90	2.30	3.78	3.11	3.90	3.00	3.82	2.34	3.86	1.90	3.44
9.15	2.38	3.88	2.32	3.78	3.11	3.93	2.96	3.83	2.40	3.86	2.08	3.40
Total,	226.41	372.48	224.46	367.16	291.41	377.84	289.21	372.85	230.07	209.48	209.48	351.24
M. E. P.	60.7		61.1		61.7		61.1		61.4		59.6	

SUCTION LIFT. No. 1.

Time.	Reading.	Time.	Reading.	Time.	Reading.	Time.	Reading.	Time.	Reading.	Time.	Reading.
9.15	122.56	1.30	122.46	5.45	122.47	10.00	122.70	2.15	122.80	6.30	122.82
9.30	122.46	1.45	122.46	6.00	122.47	10.15	122.76	2.30	122.77	6.45	122.77
9.45	122.46	2.00	122.46	6.15	122.66	10.30	122.75	2.45	122.82	7.00	122.83
10.00	122.51	2.15	122.47	6.30	122.70	10.45	122.72	3.00	122.82	7.15	122.84
10.15	122.50	2.30	122.47	6.45	122.66	11.00	122.76	3.15	122.80	7.30	122.85
10.30	122.47	2.45	122.47	7.00	122.67	11.15	122.77	3.30	122.86	7.45	122.74
10.45	122.47	3.00	122.47	7.15	122.67	11.30	122.80	3.45	122.79	8.00	122.70
11.00	122.47	3.15	122.47	7.30	122.65	11.45	122.77	4.00	122.87	8.15	122.64
11.15	122.46	3.30	122.47	7.45	122.64	12.00	122.73	4.15	122.86	8.30	122.66
11.30	122.46	3.45	122.47	8.00	122.69	12.15	122.75	4.30	122.79	8.45	122.62
11.45	122.46	4.00	122.47	8.15	122.66	12.30	122.84	4.45	122.86	9.00	122.60
12.00	122.46	4.15	122.47	8.30	122.68	12.45	122.75	5.00	122.81	9.15	122.66
12.15	122.46	4.30	122.47	8.45	122.68	1.00	122.74	5.15	122.86		
12.30	122.46	4.45	122.47	9.00	122.67	1.15	122.83	5.30	122.84		
12.45	122.46	5.00	122.47	9.15	122.67	1.30	122.88	5.45	122.78	Total,	11,896.99
1.00	122.46	5.15	122.47	9.30	122.73	1.45	122.80	6.00	122.73		
1.15	122.46	5.30	122.47	9.45	122.74	2.00	122.88	6.15	122.86	Av.,	122.65

DISCHARGE HEAD. No. 2.

Time.	Difference.	Time.	Difference.	Time.	Difference.	Time.	Difference.	Time.	Difference.	Time.	Difference.
9.15	101.8	1.45	101.15	6.15	100.75	10.45	100.65	3.15	100.70	7.45	101.00
9.30	101.7	2.00	101.00	6.30	100.70	11.00	100.85	3.30	100.45	8.00	101.95
9.45	101.6	2.15	101.05	6.45	100.95	11.15	100.90	3.45	100.60	8.15	101.85
10.00	101.5	2.30	101.1	7.00	100.70	11.30	100.70	4.00	100.40	8.30	101.90
10.15	101.75	2.45	101.25	7.15	100.75	11.45	100.85	4.15	100.35	8.45	101.80
10.30	101.50	3.00	101.2	7.30	100.85	12.00	100.70	4.30	100.35	9.00	101.60
10.45	101.5	3.15	101.05	7.45	100.85	12.15	100.55	4.45	100.55	9.15	101.00
11.00	101.7	3.30	100.9	8.00	100.80	12.30	100.30	5.00	100.55		
11.15	101.5	3.45	101.2	8.15	100.90	12.45	100.75	5.15	100.15		
11.30	101.5	4.00	100.65	8.30	100.65	1.00	101.35	5.30	99.85	Total,	9,785.79
11.45	101.5	4.15	100.69	8.45	100.50	1.15	100.35	5.45	100.45		
12.00	101.35	4.30	101.05	9.00	100.75	1.30	100.80	6.00	100.60	Av.,	100.88
12.15	101.2	4.45	100.90	9.15	100.40	1.45	100.95	6.15	100.30		
12.30	101.5	5.00	100.65	9.30	100.35	2.00	100.20	6.30	100.40		Inches of mercury.
12.45	101.15	5.15	100.80	9.45	100.60	2.15	100.35	6.45	99.30		
1.00	101.15	5.30	101.05	10.00	100.40	2.30	100.45	7.00	100.15		
1.15	101.3	5.45	101.00	10.15	100.45	2.45	100.45	7.15	100.85		
1.30	101.2	6.00	100.80	10.30	100.60	3.00	100.65	7.30	101.05		

LEVEL IN CHAMBERS ABOVE MARK. No. 26.

Time.	Reading.	Time.	Reading.	Time.	Reading.	Time.	Reading.	Time.	Reading.	Time.	Reading.
9.15	145.1	1.30	145.7	5.45	146.0	10.00	146.3	2.15	146.1	6.30	146.4
9.30	145.1	1.45	145.7	6.00	146.0	10.15	146.3	2.30	146.1	6.45	146.3
9.45	145.1	2.00	145.8	6.15	146.0	10.30	146.2	2.45	146.1	7.00	145.6
10.00	145.2	2.15	145.8	6.30	146.0	10.45	146.2	3.00	146.2	7.15	144.9
10.15	145.2	2.30	145.8	6.45	146.1	11.00	146.2	3.15	146.2	7.30	144.5
10.30	145.2	2.45	145.9	7.00	146.1	11.15	146.3	3.30	146.2	7.45	144.5
10.45	145.3	3.00	145.9	7.15	146.1	11.30	146.3	3.45	146.2	8.00	144.5
11.00	145.3	3.15	145.9	7.30	146.2	11.45	146.3	4.00	146.2	8.15	144.6
11.15	145.3	3.30	146.0	7.45	146.2	12.00	146.3	4.15	146.3	8.30	144.6
11.30	145.4	3.45	146.0	8.00	146.2	12.15	146.3	4.30	146.3	8.45	144.6
11.45	145.4	4.00	146.1	8.15	146.2	12.30	146.4	4.45	146.3	9.00	144.6
12.00	145.5	4.15	146.1	8.30	146.3	12.45	146.4	5.00	146.3	9.15	144.6
12.15	145.5	4.30	146.2	8.45	146.3	1.00	146.5	5.15	146.3		
12.30	145.5	4.45	146.2	9.00	146.3	1.15	146.2	5.30	146.3	Total,	14,149.2
12.45	145.5	5.00	146.1	9.15	146.3	1.30	146.0	5.45	146.4		
1.00	145.6	5.15	146.0	9.30	146.3	1.45	146.1	6.00	146.4	Av.,	145.87
1.15	145.6	5.30	145.9	9.45	146.3	2.00	146.1	6.15	146.4		

TEMPERATURE CONDENSING WATER AND CONDENSED STEAM. No. 18.

Time.	Temperature hot condensing water. °F.	Temperature cold condensing water. °F.	Temperature condensed steam. °F.	Time.	Temperature hot condensing water. °F.	Temperature cold condensing water. °F.	Temperature condensed steam. °F.	Time.	Temperature hot condensing water. °F.	Temperature cold condensing water. °F.	Temperature condensed steam. °F.
9.15	85	53	91	5.30	85	52	89	1.30	84	52	89
9.30	85	52	91	5.45	85	52	89	1.45	85	52	89
9.45	85	52	90	6.00	85	52	89.5	2.00	85	52	89
10.00	85	51	89.5	6.15	85	52	89.5	2.15	86	52	89
10.15	85	51	89.0	6.30	85	52	89.5	2.30	86	52	89
10.30	85	52	89	6.45	85	52	89	2.45	86	52	89
10.45	85	51	89	7.00	85	52	89	3.00	86	52	89
11.00	85	52	89	7.15	85	52	89	3.15	86	52	89
11.15	85	52	89	7.30	85	52	89	3.30	86	52	89
11.30	85	51	89	7.45	85	52	89	3.45	86	52	89
11.45	85	52	89	8.00	85	52	89.5	4.00	85	52	89
12.00	85	52	89.5	8.15	85	52	89.5	4.15	85	52	89
12.15	85	52	89	8.30	85	52	89.5	4.30	86	52	89
12.30	85	52	89	8.45	85	52	89.5	4.45	86	52	89
12.45	85	52	89	9.00	85	52	89.5	5.00	85	52	89
1.00	85	52	89.5	9.15	84	52	89.5	5.15	85	52	89
1.15	85	51	89.5	9.30	85	52	89	5.30	86	52	89
1.30	85	52	89.5	9.45	85	52	89	5.45	86	52	89
1.45	85	52	89.5	10.00	85	52	89	6.00	86	52	89
2.00	85	52	89.5	10.15	85	52	89	6.15	86	52	89
2.15	84	52	89	10.30	85	52	89	6.30	86	52	89
2.30	85	52	89.5	10.45	85	52	89	6.45	86	52	89
2.45	85	52	89.5	11.00	85	52	89	7.00	86	52	89
3.00	85	52	89.5	11.15	85	52	89	7.15	86	52	89
3.15	85	52	89.5	11.30	85	52	89	7.30	86	52	89
3.30	85	52	89.5	11.45	85	52	89	7.45	86	52	89
3.45	84	51	89.5	12.00	85	52	89	8.00	86	52	89
4.00	85	52	90	12.15	85	52	89	8.15	86	52	91
4.15	85	52	89.5	12.30	85	52	89	8.30	86	52	91
4.30	85	52	89	12.45	85	52	89.5	8.45	86	52	91
4.45	85	52	89.5	1.00	85	52	89.5	9.00	86	52	91
5.00	85	52	89	1.15	84	52	89.5	9.15	86	52	91
5.15	85	52	89								

COUNTER, PRESSURES, ETC. No. 3.

Time.	Revolutions.	Pressure in first receiver.	Pressure in second receiver.	Pressure at throttle.	Vacuum in condenser.	Pressure in L. P. jacket.	Time.	Revolutions.	Pressure in first receiver.	Pressure in second receiver.	Pressure at throtile.	Vacuum in condenser.	Pressure in L. P. jacket.
8.30	....	....	....	86	....	....	10.15	762	45.5	2.2	179	27.31	100
8.45	....	....	....	82	....	....	10.30	763	46	2.4	179	27.23	
9.00	....	....	....	98	....	....	10.45	761	46	2.2	175	27.29	
9.15	....	49	2.5	175	27.15	100	11.00	760	45.8	2.4	180	27.24	
9.30	733	48	2.5	180	27.20		11.15	761	46	2.2	179	27.31	100
9.45	757	48	2.5	180	27.20		11.30	762	46	2.5	180	27.22	
10.00	759	48	2.5	179	27.21		11.45	761	46	2.5	179	27.25	
10.15	758	48	2.4	177	27.24	100	12.00	761	45.5	2.3	174	27.26	
10.30	760	48	2.3	178	27.22		12.15	760	45.8	2.4	179	27.22	100
10.45	758	48	2	179	27.25		12.30	761	45	2.3	178	27.22	
11.00	759	48	2	179	27.22		12.45	760	46	2.5	178	27.20	
11.15	759	48	2.2	179	27.22	100	1.00	760	46	2.5	175	27.16	
11.30	761	48	2.2	178	27.25		1.15	760	45	2	178	27.21	100
11.45	760	48	2.2	179	27.22		1.30	760	46	2.5	178	27.21	
12.00	760	48	2.1	180	27.25		1.45	757	46	2.5	170	27.22	
12.15	760	48	2.2	179	27.25	100	2.00	763	48	2.3	179	27.21	
12.30	761	48	2.2	180	27.25		2.15	759	47	2.4	180	27.22	100
12.45	761	48	2.2	180	27.25		2.30	761	47	2.3	179	27.26	
1.00	763	48	2.2	180	27.26		2.45	761	47	2.3	179	27.25	
1.15	763	46	2.1	180	27.25	100	3.00	761	46	2.3	175	27.24	
1.30	758	45	2.3	180	27.25		3.15	761	45	2.3	179	27.22	100
1.45	760	46	2.5	179	27.23		3.30	761	46	2	178	27.23	
2.00	760	46	2.5	179	27.25		3.45	757	45	2.3	178	27.22	
2.15	759	46	2.5	180	27.23	100	4.00	757	47	2	178	27.22	
2.30	760	46	2.5	175	27.23		4.15	760	46	2	179	27.22	100
2.45	760	46	2.5	179	27.22		4.30	756	46	2	179	27.23	
3.00	760	46	2.5	179	27.25		4.45	758	46	2.5	179	27.21	
3.15	758	46	2.5	180	27.25	100	5.00	757	47	2.5	178	27.26	
3.30	760	46	2.5	179	27.22		5.15	757	45	2.5	176	27.22	100
3.45	758	46	2.5	180	27.22		5.30	745	50	3	140	27.22	
4.00	757	46	2.5	179	27.25		5.45	749	50	3	149	27.18	
4.15	757	45	2.5	179	27.22	100	6.00	760	47	2.5	170	27.22	
4.30	756	46	2.5	179	27.25		6.15	760	47	2	179	27.28	107
4.45	756	46	2.5	180	27.25		6.30	758	47	2.5	179	27.25	
5.00	760	46	2.5	179	27.25		6.45	759	45	2	178	27.25	
5.15	759	46	2.4	179	27.29	100	7.00	761	44	1.5	179	27.27	
5.30	760	46	2.5	175	27.37		7.15	759	44	1.5	178	27.22	97
5.45	760	46	2.5	179	27.30		7.30	759	47	2.5	178	27.20	
6.00	761	46	2.3	179	27.32		7.45	758	46	2.5	178	27.22	
6.15	760	45.5	2.3	178	27.29	100	8.00	758	46	2.5	174	27.21	
6.30	760	45	2.3	178	27.24		8.15	755	46	2.5	176	27.21	97
6.45	760	45.4	2.3	178	27.34		8.30	757	46	2.5	179	27.22	
7.00	760	45.5	2.3	180	27.30		8.45	757	46	2.5	178	27.22	
7.15	760	45.5	2.3	179	27.29	100	9.00	749	49	3	160	27.21	
7.30	758	46	2.4	179	27.31		9.15	735	55	4.5	110	27.09	90.
7.45	760	46	2.4	179	27.36								
8.00	760	46	2.5	175	27.35		Total,	72,843					
8.15	760	45.3	2.5	178	27.31	100							
8.30	763	46	2.5	180	27.28		Totals,		4,506.6	230.5	17,143	2,642.71	2,491
8.45	763	46	2.5	180	27.31								
9.00	762	45.5	2.4	179	27.27		Av.,		46.46	2.38	176.73	27.25	99.6
9.15	763	45	2.3	180	27.24	100							
9.30	762	46	2.1	180	27.25								
9.45	762	45.5	2.3	179	27.31								
10.00	762	45.8	2.2	179	27.32								

Cor. av., $\frac{1}{175.7}$

Reading of counter at 9.09, 422,741.
Reading of counter at 9.26, 496,257.

WEIGHT AIR PUMP WATER. No. 5.

Barrel No. 1 full.	No. 1 empty.	Difference No. 1.	Time when emptied.	Barrel No. 2 full.	No. 2 empty.	Difference No. 2.	Time when emptied.	Barrel No. 1 full.	No. 1 empty.	Difference No. 1.	Time when emptied.	Barrel No. 2 full.	No. 2 empty.	Difference No. 2.	Time when emptied.
1,001	408	593	On starting engine.	620	227	303	....	989	421	568	10.55	1,280	237	1,043	11.25
1,245	1,001	244	9.15	536	270	266	....	1,175	420	755	11.12	863	239	624	12.00
864	454	410	....	591	257	334	....	1,288	416	872	11.35	864	242	622	12.10
910	504	406	....	995	264	731	....	1,200	476	724	11.50	1,275	238	1,037	12.20
1,143	496	647	....	879	267	612	....	1,383	420	963	12.07	1,131	239	892	12.30
1,279	450	829	....	1,182	280	902	10.30	1,502	429	1,073	12.25	1,140	244	896	12.44
1,609	520	1,089	10.20	1,372	242	1,130	11.00	1,098	430	688	12.35	1,312	242	1,070	1.00
1,700	443	1,257	10.50	1,290	253	1,037	11.25	1,483	416	1,067	12.55	1,097	246	851	1.25
1,822	502	1,320	11.15	1,353	240	1,113	11.55	1,379	429	950	1.14	1,153	258	895	1.45
1,832	463	1,369	11.40	1,360	240	1,120	12.20	1,645	454	1,191	1.36	871	270	601	2.07
1,869	438	1,431	12.10	1,391	254	1,137	12.55	1,120	480	640	1.58	795	251	514	2.21
1,840	421	1,419	12.40	1,380	248	1,132	1.15	1,154	479	675	2.14	1,175	253	922	2.35
1,923	443	1,480	1.05	1,330	239	1,091	1.55	1,264	472	792	2.29	1,097	240	857	2.55
1,886	432	1,454	1.40	1,391	260	1,131	2.10	1,677	470	1,207	2.44	1,085	240	844	2.30
1,900	454	1,446	2.05	1,383	256	1,027	2.40	1,195	454	741	3.08	790	250	540	3.36
1,934	483	1,451	2.30	1,364	241	1,123	3.10	1,118	474	644	3.26	1,050	243	807	3.50
1,900	493	1,407	2.55	1,364	256	1,108	3.35	1,107	470	637	3.42	1,145	253	892	4.05
1,822	445	1,377	3.25	1,353	260	1,093	4.00	1,329	462	867	3.56	1,357	250	1,107	4.26
1,810	475	1,335	3.50	1,391	258	1,133	4.30	1,594	431	1,163	4.17	1,359	265	1,094	4.51
1,905	447	1,458	4.20	1,045	262	783	4.55	1,650	461	1,189	4.39	1,073	240	833	5.19
1,610	454	1,156	4.45	1,160	240	920	5.15	1,659	426	1,233	5.07	1,338	241	1,097	5.42
1,790	695	1,095	5.05	1,146	245	901	5.25	1,584	435	1,149	5.34	924	240	684	6.07
1,340	945	395	5.30	866	248	618	5.50	1,183	434	749	5.56	1,100	243	857	6.21
1,186	465	721	5.45	1,086	244	842	6.10	1,556	429	1,127	6.15	920	245	675	6.44
1,344	487	857	6.00	1,167	236	931	6.30	973	448	525	6.34	1,128	254	874	6.56
1,220	473	747	6.20	1,258	233	1,025	6.50	1,236	443	793	6.49	989	258	731	7.16
1,476	417	1,059	6.40	1,042	238	804	7.15	1,425	449	976	7.06	951	250	701	7.37
1,488	429	1,059	7.05	1,241	130	1,111	7.35	1,282	480	802	7.29	907	245	662	7.55
1,490	413	1,077	7.25	1,144	243	901	7.55	1,404	477	927	7.47	1,069	252	817	8.11
1,249	431	818	7.40	1,185	248	937	8.15	1,217	457	760	8.04	1,011	251	760	8.29
1,300	418	882	8.05	1,208	239	969	8.40	1,274	444	830	8.21	1,343	249	1,094	8.48
1,538	416	1,122	8.30	1,110	240	870	9.00	1,295	446	849	8.40	635	276	359	9.10
1,433	418	1,015	8.50	1,107	237	870	9.20	1,077	456	621	8.57	1,480	After 9.15.	845	....
1,302	419	883	9.05	1,245	241	1,004	9.40	....							
1,275	418	857	9.30	832	237	595	9.55	....							
1,168	416	752	9.50	883	236	647	10.10	....							
1,156	468	688	10.02	1,053	247	806	10.30	....							
1,187	420	767	10.18	924	242	682	10.48	....							
1,470	423	1,047	10.40	1,070	237	833	11.30	....							

Total from 9.15 to 9.15, 128,471.

Total from 9.09 to 9.26, 129,909.

CALORIMETER.

Time.	Boiler pressure.	Back pressure.	Temperature.	Quality of steam.	Time in use.	Time.	Boiler pressure.	Back pressure.	Temperature.	Quality of steam.	Time in use.
10.30	Started.					3.06	175	15	155	....	
10.40	175	16	155			3.07	175	15	155	....	
10.41	175	16	155	.988	15 min.	3.08	Shut off.				
10.42	175	16	155	....		5.52	Started.				
10.43	176	16	154.5	....		6.04	175	15	155	....	
10.44	175	16	155	....		6.05	175	15	155	....	
10.45	Shut off.					6.06	175	15	155	....	17 min.
11.47	Started.					6.07	175	15	155	....	
12.02	174	15	155	....		6.08	175	15	155	....	
12.03	174	15	155	....	20 min.	6.09	Shut off.				
12.04	174	15	155	....		7.48	Started.				
12.05	174	15	154.8	....		8.05	175	15	155.1	....	
12.06	174	15	155	....		8.06	174	15	155.2	....	
12.07	Shut off.					8.07	173	15	155.2	....	22 min.
2.46	Started.					8.08	173	15	155.2	....	
3.03	175	15	155	....		8.09	174	15	155.2	....	
3.04	175	15	155	....		8.10	Shut off.				
3.05	175	15	155	....	22 min.						

Total time in use, 159 min.

EXTRA READINGS FOR STATION NO. 18.

Time.	Temperature hot well. °F.	Temperature suction barrel in boiler room. °C.	Time.	Temperature hot well. °F.	Temperature suction barrel in boiler room. °C.	Time.	Temperature hot well. °F.	Temperature suction barrel in boiler room. °C.
10.45	151		7.15	126	54	3.45	132	54
11.00	138	50	7.30	148	52	4.00	148	54
11.15	137	40	7.45	148	53	4.15	146	54
11.30	117	50	8.00	126	54	4.30	146	52
11.45	125	50	8.15	160	57	4.45	150	53
12.00	125	50	8.30	128	53	5.00	146	55
12.15	155	50	8.45	138	53	5.15	142	53
12.30	152	45	9.00	144	53	5.30	131	54
12.45	141	55	9.15	150	52	5.45	140	52
1.00	122	53	9.30	154	54	6.00	148	50
1.15	121	53	9.45	123	56	6.15	139	49
1.30	122	52	10.00	137	54	6.30	154	54
1.45	138	51	10.15	140	53	6.45	141	51
2.00	167	60	10.30	150	56	7.00	128	52
2.15	150	31	10.45	131	58	7.15	151	48
2.30	127	56	11.00	164	52	7.30	138	57
2.45	126	56	11.15	138	53	7.45	149	52
3.00	131	55	11.30	134	55	8.00	141	55
3.15	152	54	11.45	136	56	8.15	137	52
3.30	151	50	12.00	152	59	8.30	140	48
3.45	146	55	12.15	140	58	8.45	138	48
4.00	135	57	12.30	152	57	9.00	136	54
4.15	128	54	12.45	130	54	9.15	134	50
4.30	140	54	1.00	150	54			
4.45	139	53	1.15	141	54	Total,	12,713	3,759
5.00	136	52	1.30	145	54			
5.15	125	52	1.45	144	54			
5.30	133	54	2.00	126	54	Av.,	139.7°	41.3°
5.45	121	54	2.15	142	50			
6.00	150	53	2.30	126	53			
6.15	125	53	2.45	156	54			
6.30	153	54	3.00	144	54	Cor. av.,	1 / 140.7°	
6.45	136	55	3.15	130	54			
7.00	122	53	3.30	148	53			

JACKET TESTS. MAY 2.

Time.	Reading.	Difference.	Time.	Reading.	Difference.
Engine Stopped.			Engine Running.		
h. m. s.			h. m. s.		
1, 14, 0	0.45	...	11, 49, 11	0	3.0
1, 15, 10	1.00	.55	12, 2, 50	3.0 cu. ft.	1.0
1, 21, 0	1.73	.73	12, 6, 30	4.0	1.0
1, 24, 0	1.88	.15	12, 9, 4	5.0	3.2
1, 28, 0	2.13	.25	12, 19, 5	8.2	1.8
1, 34, 0	2.37	.24	12, 27, 17	10.0	Opened valve to blow out.
1, 39, 0	2.62	.25	12, 29, 0	.03	Valve closed.
1, 44, 0	2.83	.21	12, 34, 20	1.0	.97
1, 51, 0	3.12	.29	12, 38, 55	2.0	1.00
1, 54, 0	3.24	.12	12, 42, 28	3.0	1.00
		2.79	12, 47, 34	4.0	1.00
			12, 59, 49	8.0	4.00
			1, 4, 25	9.0	1.00
			1, 9, 30	9.45	0.45

.065 average for 1 min.
For 39 min., 8.30 to 9.09 = 2.5 cu. ft.
2.5 cu. ft. × 54.41 lbs. = 136 lbs.

Total, 78′–36″. Total, 19.42 cu. ft.
Av., .247 cu. ft. per min.
Jacket steam in 1,457 min. total engine time = 360 cu. ft.
Total, 360 cu. ft. at 54.41 lbs. = 19,587 lbs.

LOW JACKET TEST.

Engine Stopped.

Time.	Reading.	Difference.
11′, 20″	.20	
41′, 20″	1.03	.83
30 min.		

Engine Running.

54, 50		.20	
5, 40	35	1.00	.80
6, 15		.18	
24, 45	30	1.00	.82
25, 15		.14	
46, 15	75	1.04	.90
47, 30		.07	
8, 30	30	1.00	.93
9, 0		.14	
11, 20			
76, 30	170 secs.	.20	.06

73′–40″ = time running. 3.51 cu. ft.

STEAM IN SMALL ENGINE. No. 20.

Time steam turned in.	Weight of cold water.	Weight of hot water.	Time steam shut off.	Weight of steam.
8.32	1,144	1,176	10.00	32
10.07	1,026	1,068	11.37	42
11.45	1,063	1,107	1.15	44
1.21	1,115	1,161	3.01	46
3.07	1,092	1,138	4.31	46
4.37	1,040	1,090	6.12	50
6.18	1,043.5	1,092	7.48	48.5
7.54	1,054	1,117	9.54	63.0
10.01	1,091	1,142	11.31	51.0
11.37	1,079	1,130	1.07	51.0
1.14	1,095	1,136	2.44	41.0
2.51	1,137	1,180	4.21	43.0
4.28	1,155	1,206	5.58	51.0
6.07	1,064	1,114	7.37	50.0
7.45	1,021	1,063	9 25	42.0
				700.5

700.5 pounds in 23.3 hours.
722 pounds in 24 hours.

DRIPS.

Separator.				First Receiver.				Second Receiver.			
High level.	Low level.	Difference.	Time.	High level.	Low level.	Difference.	Time.	High level.	Low level.	Difference.	Time.
			h. m. s.				h. m. s.				h. m. s.
.60	.15	.45	9, 00	....	.19		9, 00	....	.27		9, 00
	.43		9, 15	....	.40	.21	9, 15	....	.35	.08	9, 15
1.05		.62	10, 29, 10	1.10		.70	9, 27½	1.02		.67	12, 22, 5
	.12		10, 29, 25		.17		9, 28¾		.23		12, 24, 30
1.01		.89	12, 26	1.10		.93	9, 55	1.00		.77	3, 51, 00
	.07		12, 26, 40		.19		9, 55, 47		.06		3, 51, 50
1.07		1.00	2, 22, 30	1.10		.91	10, 24, 50	1.13		1.07	7, 13, 30
	.08		2, 22, 50		.12		10, 25, 30		.10		7, 14, 25
1.15		1.07	4, 50, 15	1.10		.98	10, 56, 25	1.10		1.00	10, 41, 10
	.09		4, 51, 10		.16		10, 57, 10		.15		10, 42, 10
1.11		1.02	7, 17, 00	1.10		.95	11, 25	1.14		.99	1, 55, 00
	.15		7, 18, 00		.08		11, 25, 40		.05		1, 56, 30
1.10		.95	9, 40, 50	1.10		1.02	11, 54, 40	1.14		1.09	5, 04, 10
	.10		9, 41, 40		.13		11, 55, 25		.05		5, 05, 30
1.18		1.08	11, 58, 00	1.10		.97	12, 22, 45	1.10		1.05	7, 56, 40
	.10		11, 59, 00		.05		12, 23, 35		.19		7, 57, 45
1.18		1.08	2, 30, 12	1.16		1.11	12, 57, 30	.68		.49	9, 15
	.20		2, 30, 40		.05		12, 58, 40		.68		.....
1.18		.98	4, 42, 20	1.13		1.08	1, 29, 30	.80		.12	9, 26
	.09		4, 44, 20		.07		1, 30, 30				
1.09		1.00	7, 26, 00	1.11		1.04	1, 47, 22				
	.08		7, 27, 50		.06		1, 48, 10				
.63		.55	9, 15	1.12		1.06	2, 26, 43				
.63	.63	0	9, 26	1.12	.08	1.04	2, 26, 30				
					.10		2, 45, 35				
				1.10		1.00	2, 46, 15				
					.10		3, 22, 30				
				1.10		1.00	3, 23, 10				
					.05		3, 49, 10				
				1.11		1.06	3, 50, 00				
					.16		4, 20, 45				
				1.16		1.00	4, 21, 30				
					.11		4, 48, 00				
				1.12		1.01	4, 48, 45				
					.12		5, 17, 00				
				1.12		1.00	5, 17, 40				
					.12		5, 45, 30				
							5, 46, 15				

DRIPS. — *Continued.*

First Receiver.				First Receiver.				Low Jacket.			
High level.	Low level.	Difference.	Time.	High level.	Low level.	Difference.	Time.	High level.	Low level.	Difference.	Time.
			h. m. s.				h. m. s.				h. m. s.
1.13		1.01	6, 13, 00						.13		9, 00
	.12		6, 13, 40	.97		.91	2, 32, 10		.70	.57	9, 15
1.16		1.04	6, 40, 30		.09		2, 32, 50	1.10		.40	9, 23, 20
	.15		6, 41, 05	1.16		1.07	2, 59, 42		.02		9, 23, 55
1.14		.90	7, 07, 15		.05		3, 00, 15	1.10		1.08	9, 46, 55
	.06		7, 07, 45	1.13		1.08	3, 28, 00		.05		9, 47, 25
1.15		1.09	7, 38, 10		.06		3, 29, 30	1.10		1.05	10, 9, 35
	.12		7, 38, 45	1.14		1.08	3, 55, 40		.02		10, 10, 5
1.15		1.03	7, 05, 30		.08		3, 56, 45	1.10		1.08	10, 27, 45
	.11		7, 06, 10	1.15		1.07	4, 23, 05		.10		10, 28, 14
1.13		1.02	8, 33, 40		.05		4, 24, 00	1.10		1.00	10, 54, 10
	.20		8, 34, 15	1.14		1.09	4, 50, 40		.14		10, 54, 40
1.13		.93	8, 41, 10		.06		4, 51, 40	1.10		.96	11, 14, 45
	.10		8, 41, 50	1.15		1.09	5, 18, 10		.14		11, 15, 16
1.16		1.06	8, 58, 30		.08		5, 19, 10	1.12		.98	11, 26
	.08		8, 59, 10	1.15		1.07	5, 51, 10		.12		11, 26, 56
1.14		1 06	9, 27, 05		.07		5, 52, 08	1.12		1.00	11, 57, 40
	.11		9, 27, 45	1.14		1.07	6, 14, 35		.15		11, 58, 20
1.16		1.05	9, 55, 30		.09		6, 16, 00	1.10		.95	12, 18, 10
	.11		9, 56, 25	1.12		1.03	6, 39, 35		.15		12, 18, 40
1.16		1.05	10, 25, 20		.07		6, 40, 40	1.12		.97	12, 20, 17
	.10		10, 26, 0	1.14		1.07	7, 07, 30		.11		12, 20, 47
1.16		1.06	10, 55, 50		.06		7, 08, 30	1.11		1.00	1, 1, 40
	.13		10, 56, 50	1.14		1.08	7, 34, 05		.11		1, 2, 10
1.14		1.01	11, 25, 00		.06		7, 35, 14	1.11		1.00	1, 23
	.08		11, 25, 40	1.14		1.08	8, 00, 30		.09		1, 23, 32
1.13		1.05	11, 52, 30		.07		8, 01, 21	1.10		1.01	1, 44, 45
	.09		11, 53, 20	1.16		1.11	8, 27, 25		.06		1, 45, 15
1.13		1.04	12, 20, 00		.05		8, 28, 30	1.15		1.09	2, 8, 50
	.07		12, 20, 50	1.08		1.03	8, 52, 22		.07		2, 9, 17
1.16		1.09	12, 49, 05		.04		8, 53, 15	1.11		1.04	2, 31, 3
	.10		12, 49, 50	.51		.47	9, 06, 10		.08		2, 31, 30
1.13		1.03	1, 17, 00		.07		9, 06, 34	1.10		1.02	2, 52, 30
	.15		1, 17, 50	.35		.28	9, 15		.07		2, 54, 10
1.14		.99	1, 42, 48		.35		.. ..	1.12		1.05	3, 15, 30
	.07		1, 43, 40	.40		.05	9, 26		.09		3, 16, 0
1.14		1.07	2, 09, 03					1.10		1.01	3, 37, 5
	.08		2, 09, 50						.09		3, 37, 35

DRIPS. — *Concluded.*

Low Jacket.				Low Jacket.				Low Jacket.			
High level.	Low level.	Difference.	Time.	High level.	Low level.	Difference.	Time.	High level.	Low level.	Difference.	Time.
			h. m. s.				h. m. s.				h. m. s.
1.12		1.03	3, 59, 15	1.14		1.06	11, 55, 35	1.14		1.09	8, 04, 05
	.02		3, 59, 45		.08		11, 56, 25		.05		8, 04, 52
1.16		1.14	4, 25, 00	1.12		1.04	12, 18, 05	1.14		1.09	8, 29, 20
	.10		4, 26, 15		.08		12, 18, 45		.06		8, 30, 10
1.18		1.08	4, 50, 00	1.12		1.04	12, 40, 30	1.12		1.06	8, 54, 00
	.09		4, 50, 35		.10		12, 41, 10		.10		8, 54, 50
1.12		1.03	5, 12, 10	1.12		1.02	1, 02, 10	.64		.34	9, 07, 40
	.03		5, 12, 50		.10		1, 02, 40		.07		9, 08, 08
1.12		1.09	5, 36, 5	1.12		1.02	1, 44, 40	.41		.34	9, 15
	.03		5, 36, 50		.09		1, 25, 40		.41		....
1.17		1.14	6, 01, 20	1.13		1.04	1, 48, 10	1.06		.65	9,26
	.08		6, 02, 00		.07		1, 49, 15				
1.12		1.04	6, 24, 05	1.14		1.07	2, 11, 29				
	.07		6, 24, 35		.06		2, 12, 05				
1.13		1.06	6, 47, 00	1.09		1.03	2, 33, 38				
	.13		6, 47, 35		.06		2, 34, 24				
1.15		1.02	7, 10, 00	1.14		1.08	2, 58, 23				
	.10		7, 10, 30		.05		2, 59, 10				
1.14		1.04	7, 33, 15	1.14		1.09	3, 23, 10				
	.08		7, 33, 55		.06		3, 23, 56				
1.12		1.04	7, 56, 20	1.14		1.08	3, 47, 00				
	.10		7, 57, 00		.05		3, 47, 38				
1.12		1.02	8, 13, 55	1.14		1.09	4, 11, 46				
	.09		8, 14, 05		.05		4, 12, 20				
1.14		1.05	9, 04, 30	1.14		1.09	4, 36, 35				
	.05		9, 05, 00		.07		4, 37, 20				
1.17		1.12	9, 29, 35	1.14		1.07	5, 01, 05				
	.05		9, 30, 20		.04		5, 02, 00				
1.12		1.07	9, 53, 40	1.14		1.10	5, 26, 15				
	.08		9, 54, 50		.06		5, 27, 23				
1.18		1.10	10, 23, 20	1.18		1.12	5, 53, 00				
	.08		10, 24, 20		.05		5, 53, 56				
1.12		1.04	10, 46, 00	1.14		1.09	6, 14, 50				
	.04		10, 46, 50		.07		6, 15, 30				
1.12		1.08	10, 09, 40	1.14		1.07	6, 43, 40				
	.10		10, 10, 15		.05		6, 44, 35				
1.12		1.02	11, 31, 45	1.14		1.09	7, 09, 40				
	.08		11, 35, 25		.04		7, 10, 42				
				1.14		1.10	7, 36, 52				
					.05		7, 38, 15				

WOOD FIRED, ASHES, ETC. No. 20.

Time.	Weight of barrow and coal.	Weight of barrow and coal, if any.	Weight of coal fired.	Weight of full barrows.	Time of full barrows.	Time.	Weight of barrow and coal.	Weight of barrow and coal, if any.	Weight of coal fired.	Weight of full barrows.	Time of full barrows.
8.30	401.5[1]										
8.30	1,717			1,717	8.30	4.30	1,575			1,575	4.30
9.00		692	1,025			5.00		1,429	146		
9.00	1,744			1,744	9.00		1,429				
9.30		1,255	489			5.30		992	437		
9.30	1,255					6.00	992				
10.00		1,196	59			6.00		692	300		
10.00	1,196					6.00	1,575			1,575	6.00
10.30		1,072	124			6.30		1,297	278		
10.30	1,072						1,297				
11.00		845	227			7.00		994	303		
11.00	845						994				
11.30		692	153	1,566	11.30	7.30		692	302		
11.30	1,566					7.30	1,674			1,674	7.30
12.00		1,212	354			8.00		1,304	370		
12.00	1,212						1,304				
12.30		692	520	1,698	12.30	8.30	955		349		
12.30	1,698					8.45		692	263		
1.00		1,473	225			8.45	1,633			1,633	8.45
1.00	1,473					9.00		1,538	95		
1.30		1,111	362				1,538				
1.30	1,111					9.30		1,155	383		
2.00		692	419	1,543	2.00	10.00	1,155		841	314	
2.00	1,543					10.00	1,653			1,653	10.00
2.30		1,173	370			10.30		1,277	376		
2.30	1,173						1,277				
3.00		908	265			11.00		946	331		
3.00	908						946				
3.15		692	216	1,659	3.00	11.15		692	254		
3.15	1,659					11.27	1,688			1,688	11.27
3.30		1,450	209			11.30		1,638	50		
3.30	1,450						1,638				
4.00		1,085	365			12.00		1,312	326		
4.00	1,085						1,312				
4.30		692	393			12.30		1,015	297		
							1,015				
						1.00		692	323		

[1] 401.5 = pounds of wood.

WOOD FIRED, ASHES, ETC. No. 20. — *Continued.*

Time.	Weight of barrow and coal.	Weight of barrow and coal, if any.	Weight of coal fired.	Weight of full barrows.	Time of full barrows.	Time.	Weight of barrows and coal.	Weight of barrows and coal, if any.	Weight of coal fired.
1.30	1,442	1,018	424	1,442	1.03	8.30	1,259	962	297
2.00	1,018	692	326			9.00	962	774	188
2.05	1,566			1,566	2.05				
2.30		1,090	476						
3.00	1,090	865	225						
3.12	865	692	173						
3.30	1,714	1,576	138	1,714	3.15				
4.00	1,576	1,165	411						
4.30	1,165	842	323						
4.47	842	692	150	1,662	4.47				
5.00	1,662	1,417	245						
5.30	1,417	1,037	380						
5.45	1,037	823	214						
5.49	823	692	131	1,587	5.50				
6.00	1,587	1,387	200						
6.30	1,387	1,164	223						
7.00	1,164	903	261						
7.19	903	692	211						
7.30	1,725	1,636	89	1,725	7.23				
8.00	1,536	1,259	377						

Total, 16,734 + 161 = 16,895 pounds fired, including wood.

Coal and Ashes (from grate).

Weight of barrow No. 1, and refuse.	Weight of barrow No. 1, empty.	Difference.	Weight of barrow No. 2, and refuse.	Weight of barrow No. 2, empty.	Difference.
248	138	110	203.5	89	114.5

From under the grate.

Weight of barrow No. 1, full.	Weight of barrow No. 1, empty.	Difference.	Weight of barrow No. 2, full.	Weight of barrow No. 2, empty.	Difference.
300	138	162.0	233	89	144.0
285	138	147.0	238.5	89	149.5
285	138	147.0	252.5	89	163.5
288.5	138	150.5	....	...	....

Total weight from grate 224.5 pounds, $\frac{1}{4}$ of 224.5 considered good coal = 56.0 pounds.
Total weight from ash-pit 1,063.5 pounds, $\frac{1}{17}$ of 1,063.5 good coal = 63 pounds.

BAROMETER TEMPERATURES. No. 24.

Time.	Barometer.	Temperature of room. °C.	Temperature of outside air. °C.	Time.	Barometer.	Temperature of boiler room. °C.	Temperature of outside air. °C.	Time.	Barometer.	Temperature of boiler room. °C.	Temperature of outside air. °C.
		No. 62,354 Cor.	No. 61,501 Cor.								
		0°–0.2	0°–0.1	6.15	30.29	24.9	6.0	4.15			—0.2
		100°–0.3	100°–0.0	6.30	30.29	25.3	6.0	4.30	30.23	21.0	—0.1
9.00		22.1		6.45			5.9	4.45		21.5	—0.4
9.15		25.0	8.7	7.00		26.0	5.8	5.00	30.23		—0.1
9.30		25.0	9.2	7.15		26.2	5.6	5.15			—0.2
9.45		26.5	8.9	7.30		26.1	5.6	5.30		21.6	0.0
10.00		26.8	9.0	7.45	30.29		5.0	5.45	30.23	20.1	0.2
10.15		26.8	9.3	8.00		24.8	4.2	6.00	30.24		1.0
10.30		27.0	9.8	8.15	30.29	24.4	4.1	6.15			1.5
10.45		26.8	9.8	8.30			3.8	6.30		21.9	2.5
11.00		27.3	10.3	8.45	30.29	25.2	3.0	6.45	30.25	23.0	3.1
11.15	30.27	27.2	10.5	9.00	30.29	25.6	2.6	7.00			3.9
11.30		26.8	10.1	9.15			2.4	7.15			4.8
11.45		26.8	10.0	9.30		25.3	2.4	7.30		24.0	5.1
12.00		26.8	10.0	9.45		25.3	2.0	7.45	30.25	24.0	5.3
12.15		27 0	9.6	10.00			2.6	8.00			6.9
12.30		27.1	9.4	10.15	30.27		2.2	8.15			6.9
12.45			9.0	10.30		24.5	1.8	8.30		25.0	7.5
1.00	30.30		9.7	10.45		24.5	2.0	8.45	30.23	25.0	8.0
1.15		25.2	9.7	11.00	30.26		1.5	9.00			8.1
1.30			8.7	11.15			1.2	9.15			8.9
1.45			8.5	11.30		24.6	0.8				
2.00			8.1	11.45		24.3	0.8				
2.15			9.0	12.00	30.25		1.5	Total,	907.61	1,381.7	405.6
2.30		26.8	8.1	12.15	30.25		1.0				
2.45	30.30		8.2	12.30		24.1	1.2	Av.,	30.25	24.7	4.2
3.00			8.1	12.45	30.25	23.5	0.7				
3.15			8.2	1.00			0.5				
3.30		25.6	7.8	1.15			0.8				
3.45	30.29	26.0	7.5	1.30	30.25	23.4	0.7				
4.00			7.5	1.45		23.9	0.2				
4.15		25.5	7.4	2.00	30.24		0.2				
4.30		25.5	7.1	2.15			0.0				
4.45	30.29			2.30		24.0	0.1				
5.00	30.29		7.0	2.45	30.24	23.5	0.0				
5.15		25.2	6.8	3.00			0.0				
5.30		25.5	6.8	3.15			—0.2				
5.45			6.7	3.30	30.23	23.0	—0.5				
6.00			6.5	3.45		21.9	—0.3				
				4.00	30.23		—0.8				

BOILER WATER AND MAKE-UP. No. 19.

Barrel No. 1 full.	No. 1 empty.	Difference No. 1.	Time when emptied.	Barrel No. 2 full.	No. 2 empty.	Difference No. 2.	Time when emptied.
875	421	454	Engine test began.				
1,146	875	271	9.15	815	390	425	9.15
935	430	505	....	1,353	370	983	9.30
1,310	432	878	....	718	388	330	9.45
1,305	427	878	10.15	1,247	375	872	10.00
1,311	425	886	10.45	1,404	418	986	10.30
1,351	411	940	11.00	1,515	386	1,129	10.50
1,205	405	800	11.15	1,450	387	1,063	11.10
1,510	409	1,101	11.40	1,313	372	941	11.25
1,510	416	1,094	12.05	1,533	390	1,143	11.45
1,470	419	1,051	12.30	1,523	383	1,140	12.15
1,047	427	620	12.40	821	380	441	12.35
1,321	432	889	12.50	1,219	384	835	12.45
1,512	429	1,083	1.10	1,560	360	1,200	12.55
1,485	720	765	1.45	1,526	718	808	1.30
1,500	417	1,083	2.00	1,551	381	1,170	1.50
1,090	432	658	2.10	853	390	463	2.05
1,440	422	1,018	2.20	942	367	575	2.15
1,512	738	774	2.35	1,538	371	1,167	2.30
1,565	432	1,133	3.05	1,542	1,209	333	2.55
1,512	417	1,095	3.25	1,653	374	1,279	3.10
....	....	....	....	1,516	377	1,139	3.30
1,512	421	1,091	3.40	1,548	370	1,178	3.55
1,422	415	1,007	4.10	1,520	373	1,147	4.25
1,565	408	1,157	4.30	1,563	362	1,201	4.40
1,505	410	1,095	4.45	1,550	780	770	4.50
1,507	471	1,036	5.10	1,633	393	1,240	5.20
1,537	426	1,111	5.30	1,628	396	1,232	5.35
1,531	430	1,101	5.45	1,573	392	1,181	6.00
1,530	479	1,051	6.20	1,636	383	1,253	6.30
1,416	413	1,003	6.35	1,184	392	792	6.40
1,132	417	715	6.45	1,515	384	1,131	7.00
1,534	827	707	7.15	1,694	1,295	399	7.20
1,480	1,410	70	7.22	1,705	1,540	165	7.25
1,570	475	1,095	7.30	1,635	565	1,070	7.35
1,500	729	771	7.50	1,632	363	1,269	8.00
1,507	463	1,044	8.05	1,177	385	792	8.15
1,035	432	603	8.20	890	397	493	8.25
1,145	424	721	8.30	1,556	392	1,164	8.40

BOILER WATER AND MAKE-UP. No. 19. — *Continued.*

Barrel No. 1 full.	No. 1 empty.	Difference No. 1.	Time when emptied.	Barrel No. 2 full.	No. 2 empty.	Difference No. 2.	Time when emptied.
1,534	436	1,098	8.55	1,624	376	1,248	9.10
1,513	416	1,097	9.15	1,003	388	615	9.20
1,010	421	589	9.25	1,007	383	624	9.30
1,077	420	657	9.40	1,650	662	988	9.50
1,534	800	734	10.00	1,618	385	1,233	10.10
1,547	413	1,134	10.15	1,019	372	647	10.20
763	408	355	10.30	520	372	148	10.35
560	400	160	10.38	1,030	369	661	10.40
1,473	455	1,018	10.45	1,590	382	1,208	11.00
1,322	413	909	11.15	1,578	397	1,181	11.25
1,541	420	1,121	11.40	1,652	366	1,286	11.55
1,543	414	1,129	12.00	1,504	386	1,118	12.05
1,103	403	700	12.15	1,092	364	728	12.20
1,118	415	703	12.25	1,209	390	819	12.35
1,243	411	832	12.45	1,065	368	697	12.50
1,368	408	960	1.04	1,138	361	777	1.12
1,017	407	610	1.21	1,330	369	961	1.30
1,242	409	833	1.38	1,080	368	712	1.45
955	417	538	1.50	776	369	407	1.53
807	407	400	1.57	905	363	542	2.00
1,086	411	675	2.03	1,107	362	745	2.08
868	405	463	....	966	364	602	2.20
1,088	416	672	2.26	1,083	362	721	2.34
970	412	558	2.42	740	452	288	2.50
918	412	506	2.53	783	372	411	3.00
812	404	408	3.02	1,200	345	855	3.08
1,158	405	753	3.15	1,145	362	783	3.22
1,080	412	668	3.30	1,047	356	691	3.39
1,079	412	667	3.45	1,084	359	725	3.50
815	405	410	3.56	776	348	428	4.02
857	407	450	4.05	811	359	452	4.12
856	414	442	4.20	1,060	361	699	4.25
1,139	407	732	4.30	1,000	350	650	4.36
1,047	403	644	4.45	1,008	363	645	4.50
1,017	410	607	4.56	961	357	604	5.04
975	410	565	5.10	932	355	577	5.15
953	410	543	5.22	940	352	588	5.27
1,461	401	1,060	5.37	1,195	346	849	5.42
978	402	576	5.47	751	355	396	5.53
650	411	239	5.54	952	351	601	5.58

BOILER WATER AND MAKE-UP. No. 19. — *Concluded.*

Barrel No. 1 full.	No. 1 empty.	Difference No. 1.	Time when emptied.	Barrel No. 2 full.	No. 2 empty.	Difference No. 2.	Time when emptied.
1,005	404	601	6.02	988	347	641	6.10
785	421	364	6.15	585	341	244	6.18
530	408	122	6.19	555	342	213	6.20
687	405	282	6.25	698	367	331	6.27
617	407	210	6.29	680	350	330	6.31
850	411	439	....	1,390	570	820	6.45
1,470	404	1,066	7.06	1,390	345	945	7.10
1,152	411	741	7.17	960	345	615	7.23
1,250	409	841	7.30	1,366	346	1,020	7.45
1,295	438	857	7.50	1,216	350	866	7.58
1,085	412	673	8.03	1,235	345	890	8.12
1,301	409	892	8.20	1,346	355	991	8.35
1,121	411	710	8.50	1,510	817	693	9.10
1,558	1,230	328	9.15	1,462	700	762	9.25
1,230	567	663	9.25				

Water weighed for boiler for entire test on boiler, including make-up = 151,060 lbs.
Leakage of feed pump = 1,440.
Total water fed, 149,620 lbs.

Make-up barrel full.	Empty.	Difference.	Time when emptied.
495	111	384	8.30
457	127	330	10
406	123	283	9.15
460	121	339	9.15
491	117	374	9.30
472	117	355	....
488	106	382	9.45
469	120	349	....
487	116	371	10.00
479	117	362	10.15
505	116	389	10.30
510	116	394	11.15
478	114	364	12.40
483	112	371	12.45
498	115	383	2.10
488	110	378	2.20
507	110	397	3.05
519	112	407	4.22
509	110	399	5.50
507	107	400	6.03
506	107	399	8.25
511	104	407	8.50
510	195	315	9.00

7,535 = make-up during 24 hours engine test.
997 = make-up before engine started.

8,532 = total make-up 24.93 hours.

TEMPERATURE OF FEED AND GASES BEFORE ENTERING AND AFTER LEAVING ECONOMIZER.

DRAUGHT. Nos. 21 and 19.

Time.	Temperature of feed before. °F.	Temperature of feed after. °F.	Temperature of gases before. °F.	Temperature of gases after. °F.	Draught in inches of water.
9.00	170.8	179.8	322	206	....
9.15	128	184	378	214	....
9.30	99	189.5	404	223	....
9.45	108.5	194.4	404	215	....
10.00	96	194.8	398	208	....
10.15	111.5	194.8	399	203	....
10.30	101.8	191	402	198	....
10.45	115.4	182	405	196	....
11.00	132.8	171.1	403	195	.500
11.15	128	165	416	198	.060
11.30	112	162	422	203	.358
11.45	120.1	164.1	425	208	.098
12.00	133.7	170.1	428	212	.352
12.15	126.0	176	430	214	.236
12.30	129.8	179.8	434	215	.300
12.45	114	180	438	217	.268
1.00	128.1	176.5	436	212	.208
1.15	125.6	174.4	426	208	.296
1.30	123.2	176.3	424	204	.270
1.45	122	180.2	421	201	.322
2.00	128.3	182.0	422	202	.266
2.15	124.2	183.6	440	204	.060
2.30	129.7	182.0	437	198	.110
2.45	133.6	182.3	434	195	.322
3.00	129.1	184	430	190	.308
3.15	124.0	183.5	431	190	.408
3.30	130.1	184.2	437	192	.380
3.45	137.0	184.1	435	191	.352
4.00	136.0	183.9	434	191	.360
4.15	123.2	184.0	435	191	.346
4.30	126.7	184.5	430	189	.402
4.45	128.0	185.0	430	193	....
5.00	128.0	184.0	445	192.5	.246
5 15	127.0	185.0	440	194	.390
5.30	126.0	186.0	440	194	.090
5.45	132.2	184.0	446	196	.126
6.00	130.2	184.0	447	196	.090

Time.	Temperature of feed before. °F.	Temperature of feed after. °F.	Temperature of gases before. °F.	Temperature of gases after. °F.	Draught in inches of water.
6.15	126.0	185.0	425	195	.446
6.30	122.0	186.0	452	198	.064
6.45	133.0	187.0	460	200	.442
7.00	124.0	189.0	464	203	.400
7.15	130.0	192.0	466	210	.414
7.30	126.0	192.4	473	213	.454
7.45	120.0	197.5	475	219	.370
8.00	128.5	200.4	494	231	.410
8.15	125.0	204.0	496	240.5	.374
8.30	140 0	206.0	502	243	.130
8.45	123.5	206.0	493	236	.364
9.00	125.5	206.0	490	235	.148
9.15	125 4	207.5	497	237.5	.504
9.30	132.4	206.5	504	243	.090
9.45	137.0	207.0	507	243	.398
10.00	132.0	208.5	494	241	.434
10.15	125.0	208.3	508	245	.490
10.30	128.5	207.4	519	252	.170
10.45	136.0	207.5	518	252	.406
11.00	132.5	207.5	516	255.5	.458
11.15	128.0	210.0	519	256.0	.238
11.30	128.0	211.7	518	254.0	.174
11.45	128 3	217.5	520	257.0	.536
12.00	127.0	218.0	524	256.5	.130
12.15	137.0	217.5	526	256.0	.534
12.30	134.0	212.0	520	255.0	.541
12.45	132.0	211.0	530	258.0	.578
1.00	126.0	212.0	532	258.0	.598
1.15	126.0	213.0	530	253.0	.500
1.30	130.0	214.0	516	245.0	.636
1.45	132.0	217.0	518	246.0	.576
2.00	134.0	212.0	526	250.0	.580
2.15	128.0	212.0	534	254.0	.460
2.30	126.0	210.0	530	251.0	.208
2.45	124.0	208.0	530	244.0	.560
3.00	135.0	208.0	510	246.0	.478
3.15	124.0	207.0	516	236.0	.510
3.30	125.0	207.0	524	254.0	.502
3.45	128.0	207.0	530	258.0	.496

Time.	Temperature of feed before. °F.	Temperature of feed after. °F.	Temperature of gases before. °F.	Temperature of gases after. °F.	Draught in inches of water.
4.00	124	207	536	264	.530
4.15	132	207	542	264	.540
4.30	122	209	554	203	.526
4.45	132	212	550	268	.534
5.00	134	212	556	266	.284
5.15	134	214	554	264	.518
5.30	132	212	510	268	.508
5 45	127	210	520	268	.584
6.00	108	210	550	272	.408
6.15	116	210	554	272	.558
6.30	117	210	558	270	.414
6.45	136	212	546	267	.416
7.00	135	216	540	264	.558
7.15	123	213	544	265	.560
7.30	128	216	552	267	.604
7.45	132	216	554	270	.524
8.00	134	216	560	268	.516
8.15	134	216	552	268	.528
8.30	117	213	558	266	.522
8.45	118	214	560	264	.412
9.00	110	215	552	262	.408
9.15	111	212	522	246	.234
9.30	121	210	490	228	.190
Total,	12,521.7	19,630.1	47,848	22,842.5	34.195
Av.,	126.5	198.3	483	231	.375
			19.0	2	
Cor. av.,	127.0	198.3	502.0	233.0	

WEIGHT OF COAL, BOILER PRESSURE, ETC. No. 20.

Time.	Boiler pressure. (Lbs.)	Temperature of returns at boiler. °F.	Time.	Boiler pressure. (Lbs.)	Temperature of returns at boiler. °F.	Time.	Boiler pressure. (Lbs.)	Temperature of returns at boiler. °F.
8.30	91	322	6.00	184	373	3.30	184	373
8.45	86	321	6.15	184	373	3.45	185	373
9.00	99	329	6.30	183	373	4.00	183	373
9.15	173	366	6.45	183	373	4.15	184	373
9.30	184	374	7.00	185	373	4.30	183	373
9.45	185	374	7.15	185	373	4.45	184	373
10.00	185	374	7.30	184	373	5.00	185	373
10.15	185	374	7.45	184	373	5.15	181	373
10.30	185	374	8.00	185	373	5.30	145	355
10.45	185	374	8.15	184	373	5.45	160	360
11.00	185	374	8.30	185	373	6.00	183	373
11.15	185	374	8.45	185	373	6.15	185	373
11.30	185	374	9.00	185	373	6.30	185	373
11.45	185	374	9.15	185	373	6.45	185	373
12.00	185	374	9.30	185	373	7.00	184	373
12.15	185	374	9.45	185	373	7.15	183	373
12.30	185	374	10.00	185	373	7.30	184	373
12.45	185	374	10.15	185	373	7.45	185	373
1.00	185	374	10.30	184	373	8.00	185	373
1.15	185	374	10.45	185	373	8.15	181	373
1.30	185	374	11.00	185	373	8.30	185	373
1.45	185	374	11.15	185	373	8.45	182	373
2.00	185	374	11.30	185	373	9.00	163	365
2.15	184	374	11.45	185	373	9.15	117	343
2.30	184	374	12.00	184	373	9.25	93	325
2.45	185	374	12.15	184	373			
3.00	184	374	12.30	183	373			
3.15	184	374	12.45	184	373	Total,	18,073	37,432
3.30	184	374	1.00	180	373			
3.45	185	374	1.15	185	373			
4.00	184	374	1.30	184	373	Av.,	178.9	370.6
4.15	184	374	1.45	175	373	Cor. av.,		369.6
4.30	185	374	2.00	183	373			
4.45	184	374	2.15	184	373			
5.00	185	373	2.30	185	373			
5.15	183	373	2.45	185	373			
5.30	184	373	3.00	184	373			
5.45	183	373	3.15	184	373			

FLUE GASES. Nos. 22 and 23.

Time.	CO_2.	O.	CO.	Time.	CO_2.	O.	CO.
10.35	12.7	5.1	0	9.00	11.0	9.0	0
	12.6	5.2	0	9.15	10.2	11.0	0
11.05	11.5	7.9	0	9.30	14.6	2.8	0
11.15	15.1	3.4	0	9.45	8.2	1.1	0 6
11.30	11.8	5.8	0	10.00	14.6	1.8	0.2
11.45	13.2	5.6	0	10.15	9.8	10.2	0
12.00	10.6	4 4	0	10.30	10.4	9.4	0
12.15	13.0	5.0	0	10.45	7.5	12.7	0.2
12.30	13 6	1.4	1.4	11.00	10.2	9 6	0
12.45	12.6	2.8	0.2	11.15	9.2	9.2	0.4
1.00	7.6	12.4	0	11.30	7.4	13.6	0
1.15	10.4	4.8	0.4	11.45	10.8	8.6	0
1.30	14	5.2	0	12.00	10.0	9.8	0
1.45	—	—	—	12.15	8.8	10.4	0
2.00	12.8	5.2	0	12.30	9.2	9.5	0
2.15	13.9	3.7	0	12.45	9.5	1.7	0
2.30	13.3	1.5	0.2	1.00	14.6	2.9	0
2.45	12.5	4.1	0	1.15	9.7	3.5	0
3.00	13.2	5.1	0	1.30	8.7	7.9	0.3
3.15	11.1	7.3	0	1.45	2.0	8.0	0
3.30	13.3	1.3	0.8	2.00	3.5	13.5	0.2
3.45	—	—	—	2.15	5.0	13.0	0
4.00	12.4	2.7	0.2	2.30	15.0	5.0	0
4.15	14.8	3.9	0	2.45	6.5	9.5	0
4.30	13.3	1.9	0.2	3.00	12.0	6.0	0.4
4.45	13.1	2.3	0.4	3.15	5.0	12.5	0
5.00	6.2	13.1	0.7	3.30	6.5	9.6	0
5.15	11.9	7.9	0	3.45	3.5	10.0	0
5.30	15.2	2 8	0.2	4.00	9.0	10.0	0.7
5.45	15.2	2.4	0	4.15	3.5	8.5	0
6.00	15.7	2.1	0	4.30	2.5	8.2	0.1
6.15	14.8	1.1	0	4.45	2.8	7.9	0.2
6.30	10.4	9.4	0.9	5.00	2.5	6.0	0
6.45	—	—	—	5.30	2.5	10.5	0
7.00	10.0	9.4	0	6.00	8.0	10.2	0
7.15	9.9	6.7	0.8	6.30	4.5	11.5	0.1
7.30				7.00	2.0	12.3	0
7.45	6.6	12.2	0	7.30	3.5	12.0	0.5
8.00	9.6	10.4	0	8.00	4.0	11.8	0.5
8.15	8.6	11.4	0	8.30	8.0	11.0	0
8.30	15.2	3.8	0	9.00	3.0	12.0	0
8.45	15.0	1.6	0.8				

WEIR READINGS.

Time.	Hook gauges. No. 7.	Hook gauges. No. 6.	Water collected. No. 5.	Time.	Temperature.	Water column. No. 1.[1]
9.15–10	1.0348	1.0355	248.03	10.30	52.0	10.068
10–11	1.0347	1.0351	248.03	11.00	52.0	10.058
11–12	1.0351	1.0354	248.03	11.30	52.3	10.063
12–1	1.0356	1.0356	248.03	12.00	52.2	10.066
1–2	1.0359	1.0356	248.03	12.30	52.0	10.066
2–3	1.0353	1.0346	248 03	1.00	52.0	10.068
3–4	1.0338	1.0333	248 03	1.30	52.0	10.038
4–5	1.0325	1.0318	248.03	2.00	52.4	10.024
5–6	1.0291	1.0293	248.03	2.30	52.5	10.040
6–7	1.0329	1.0328	248 036	3.00	52.3	10.048
7–8	1.0327	1.0325	248.035	3.30	52.4	10.064
8–9	1.0353	1.0354	248.037	4.00	52.5	10.040
9–10	1.0309	1.0315	248 033	4.30	52.5	10.041
10–11	1.0322	1.0326	248.035	5.00	52.5	10.037
11–12	1.0316	1.0321	248.034	5.30	52.8	10.052
12–1	1.0346	1.0346	248.036	6.00	52.6	9.997
1–2	1.0271	1.0263	248.023	6.30	52.7	10.034
2–3	1.0326	1.0324	248.028	7.00	52.7	10.011
3–4	1.0296	1.0297	248 026	7.30	52.7	10.002
4–5	1.0298	1.0296	248.025	8.00	52.7	9.967
5–6	1.0226	1.0227	248.017	8.30	52.6	9.972
6–7	1.0202	1 0205	248.014	9.00	52.7	9.953
7–8	1.0227	1.0222	248.016	9.30	52.9	10.015
8–9	1.0289	1.0290	248 024	10.00	52.8	
9–9.15	1.0113	1.0089	248.008	10.30	52.8	
				11.00	52.8	Av., 10.031
Av.,	1.0310 +	1.0310 +	248.030	11.30	52.8	239.981
	246.9831	246.9835	— .015	12.00	52.9	
				12.30	52.8	Cor. av., 250.012
Cor. av.,	248.0141	248.0145	248.015	1.00	52.8	
	247.0345	247.0345	247.0345	1.30	52.8	
				2.00	52.8	
Head on weir,	.9796	.9800	.9805	2.30	52.8	
				3.00	52.9	
				3.30	52.8	
				4.00	52.8	
				4.30	52.8	
				5.00	52.8	
				5.30	52 8	
				6.00	52.8	
				6.30	52.4	
				7.00	52.4	
				7.30	52.4	

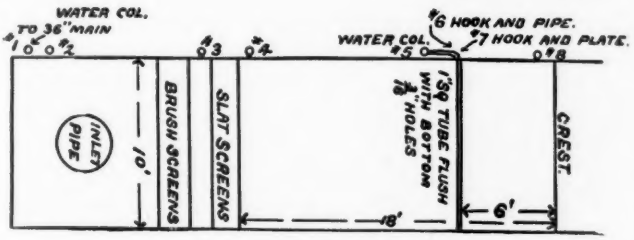


FIG. 4. SKETCH OF WEIR.

Mean height, floor to crest, 5.061′. Mean elevation of crest of weir, 247.0345′.

[1] Hourly averages from 10 A. M., May 1, to 9 A. M., May 2.

ENGLACIAL DRIFT.[1]

By W. O. CROSBY, S.B.

Received April 15, 1896.

Introduction.

Among the unsolved problems of glacial geology none, perhaps, are more important or pressing at the present time than the relative abundance and significance of the englacial drift. Although this subject has received its due share of attention in the recent literature of the science, the views of the leading glacialists are still strongly contrasted. Thus Chamberlin and others hold that the englacial drift was exceedingly scanty in amount, consisting chiefly of a few far-traveled, angular, and unglaciated bowlders now scattered over the surface of the drift; while Upham, the foremost exponent of the opposing theory, finds in the englacial drift the chief source of all the manifold forms of modified drift and also of drumlins.

The arguments of those who minimize the englacial drift are based chiefly upon the local character of the drift, the supposed paucity of englacial drift in modern glaciers, and the mechanical difficulty of accounting for a differential upward movement in the ice-sheet whereby large volumes of basal drift or ground moraine became englacial. The cogency of these arguments is beyond question; and a careful study of the recent literature satisfies me that, as the case now stands, the *onus probandi* may fairly be said to rest upon those who regard the englacial drift as an important factor in Pleistocene geology. Still, the englacial drift accounts so satisfactorily for far-traveled erratics, and the derivation from it of the modified drift is, theoretically, so relatively direct and simple, that faith in its sufficiency cannot be lightly relinquished.

In his recent paper on the "Discrimination of Glacial Accumulation and Invasion,"[2] Upham has, it seems to me, made a substantial

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[1] Reprinted from American Geologist, 17, No. 4, April, 1896.

[2] Bull. Geol. Soc. of America, 6, 343-352.

contribution to the general theory of the Pleistocene ice-sheet; and my chief purpose now is to analyze this idea that the ice-sheet was, over a considerable part of the glaciated area, formed *in situ* by snow accumulation, trace it to its logical conclusions, and show that it also throws important light upon the more special problem of the englacial drift.

Probable Early History of the Pleistocene Ice-sheet.

In this discussion a sharp distinction may properly be made between mountainous tracts, like the Adirondacks, Green Mountains, and White Mountains, and the plain or peneplain surface characteristic of the greater part of the glaciated area. The first-named topographic type, although the more exceptional, may conveniently be considered first.

In mountainous districts, or where the relief features are so strongly accentuated as to cause appreciable climatic differentiation, the general refrigeration of the climate, due chiefly, it is probable, to a marked elevation of the northern part of the continent, led first to the development of glaciers of the Alpine type in the higher valleys. These descended, under the influence of gravity, below the climatic zone in which they originated; as the level at which terminal ablation balanced the downward movement was gradually lowered, they became confluent; and finally, emerging from the mountains, they deployed upon the plain country, forming relatively sluggish or stagnant piedmont glaciers. But the extension of the piedmont glaciers by simple invasion cannot continue indefinitely, for the reason that with progressive refrigeration the annual snowfall finally exceeds the annual melting over the plain country as well as the mountains; at first near the margins of the piedmont glaciers only, but gradually extending farther and farther from them.

This cumulative snowfall, which mantled alike hills and valleys, and changed slowly through *névé* to glacial ice, must have tended in some measure to check or arrest the motion of the ice which had flowed outward from the mountains. Owing, however, to the forward motion of the piedmont glaciers, as well as to their termination on tracts where a short time before ablation had been in excess of snowfall, they must have terminated somewhat abruptly or with high marginal gradients;

and the conditions were, therefore, extremely favorable for their overriding the new and still stationary ice-fields by which they were invested, in the manner indicated by the experiments of Favre, Bailey Willis, and others, on the compression and folding of sedimentary deposits of unequal thickness or rigidity.[1] The overridden tract or zone of ice must slowly acquire the motion of the overriding sheet, and thus in its turn come to override other tracts. In fact, it seems to me very probable that this process of overriding and absorption would continue almost indefinitely, extending, possibly, over a large part of the glaciated area. The only alternative views are that the piedmont glaciers became stationary, or that they were able by simple thrust to induce motion in the embryo and still sedentary ice-sheet across a breadth of hundreds of miles. The theory of overriding lies between these extremes.

Assuming a uniform annual snowfall over the area of the sedentary ice-sheet, it is obvious that since its area is gradually extended southward by the progressive climatic refrigeration, while the annual ablation as gradually diminishes northward, its thickness must increase backward from the margin. To the surface gradient thus resulting must be added the southward gradient of the surface of the land, which was probably augmented by differential continental uplift.

If, as Upham holds,[2] and as certainly seems most probable, the precipitation of snow over the growing ice-sheet was not uniform, but greatest for the first one hundred to two hundred miles inward from the margin, the surface gradient must have culminated on these peripheral tracts, diminishing gradually backward. This condition would, obviously, favor an early beginning of outward movement or flow in the marginal zone, and tend in an equal degree to retard motion in the central area.

It seems a reasonable assumption that the period of the growth and culmination of the ice-sheet, equally with that of its waning and disappearance, must have witnessed marked climatic oscillations of long period. In fact, we would hardly be justified in supposing that the great crustal movement which gave us the Ice Age was steadily progressive, without interruption or reversal, until its final culmination.

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[1] See, also, Upham's paper on "Drumlins and Marginal Moraines of Ice-sheets," Bull. Geol. Soc. of America, 7, 22.

[2] Bull. Geol. Soc. of America, 6, 344.

During each period of climatic amelioration and increased ablation of the sedentary ice-sheet its margin must have retreated to the northward; and since the ablation must have rapidly diminished northward, snowfall exceeding ablation within a few miles of the margin, we have here another efficient cause of a high marginal gradient; that is, precipitation and ablation coöperate to accentuate the frontal slope of the ice-sheet. Now, the chief factors in determining movement of the ice-sheet were, undoubtedly, its thickness and marginal gradient. We have few reliable data derived from observations on modern ice-sheets to indicate the magnitude which these factors must attain to inaugurate movement in an ice-sheet formed *in situ* over such a dissected peneplain as is presented by the surface of a large part of Canada and the northern United States, many of the valleys having contrary or transverse directions. But the absence from a large part of the glaciated area of mountains or dominant heights of land requires us to assume that over considerable tracts the sedentary ice-sheet did eventually begin to flow without having experienced the overriding or shearing thrust of the piedmont ice-fields. The outward movement thus originating in the peripheral tracts during a period of excessive ablation must have extended backward, perhaps until it met the forward thrust of the piedmont glaciers.

During a period of active growth of a sedentary ice-sheet each annual snowfall advances its margin, and increases its thickness by amounts depending upon the distance from the margin. Although the zone of maximum precipitation does not necessarily coincide exactly with that of most rapid growth or maximum excess of precipitation over ablation, we may assume that they would not be widely separated, and that the locus of most rapid growth would, therefore, be found at a moderate distance, say one hundred to two hundred miles from the margin. If we could only know the normal ratio of vertical to horizontal or areal growth, we might, assuming that climatic oscillations began at an early period of its history, reach a definite conclusion as to the probable extent of the ice-sheet when it first began to move or flow outward. We may, however, attack the problem in another way. The equivalent of one foot of ice is, perhaps, not too large an estimate of the average annual excess of precipitation over ablation on the zone of maximum growth. Warm periods may arrest and reverse the areal growth while the central tracts continue to increase in thickness, though possibly at a diminished rate, thus

accentuating the frontal slope; that is, while cold periods must mean, on a plain country, relatively rapid horizontal growth and therefore a growth unfavorable to early movement, the ice-sheet becoming proportionally thinner, a moderately warm period following a cold one means continued growth in thickness with a great reduction of area and hence a growth especially favorable to early movement, the ice-sheet becoming proportionally thicker. It seems probable, therefore, that a warm period following a cold period of two or three thousand years duration would induce movement in the sedentary ice-sheet, and that movement at this early period might affect almost simultaneously the peripheral and central tracts.

Assuming now that movement of the ice-sheet was inaugurated during a warm period, and that the southern margin of the ice has retreated far to the north through ablation, developing a bold and aggressive front, it is obvious that the succeeding cold period must have caused a rapid extension of sedentary ice southward from the front of the moving sheet, and the former would inevitably be progressively overridden and absorbed by the latter. It may be noted, also, that these phenomena would be repeated with each recurring climatic cycle. This section may be summarized as follows:

The Pleistocene ice-sheet was formed *in situ*, by snow accumulation, over the main part of the plain country within the glaciated area. The motion which this sedentary ice-sheet subsequently acquired probably originated in several ways.

1. In the vicinity of the mountainous tracts, through its being progressively overridden and absorbed by piedmont glaciers.

2. At a distance from mountains and independently of piedmont glaciers, by the steepening of the marginal gradient, chiefly through increased ablation due to climatic amelioration.

3. The cold period following each period of marked climatic amelioration and consequent recession of the margin of the ice-sheet must have spread a new sedentary ice-sheet over the deglaciated area, which would be progressively overridden and absorbed by the re-advance of the older sheet.

Basal Relations of a Sedentary Ice-sheet.

During the slow accumulation of the ice-sheet, and before it began to move, the ground beneath it, which must have been saturated with water, was probably frozen solid to a considerable depth, possibly

nearly if not quite to the bottom of the residuary soil or other surface detritus; that is, down to the firm rocks. There could have been no original plane of separation or movement between this frozen soil and the overlying ice-sheet, for the ice did not merely rest *on the detritus*, but extended down through it to the lower limit of frost. This point will probably be conceded by all who have noted the tenacity with which ice in winter adheres to the ground, pavements, etc., when the temperature is below freezing.

Ice, in the thin sheets with which we are familiar, separates readily from the underlying soil in mild weather, while the subsoil still remains frozen, for the simple reason that the solar heat passing downward through the ice is arrested by the surface of the ground, causing a local rise of temperature along the contact between the ice and frozen soil. The operation of this principle evidently depends upon the thermal diaphaneity of the ice, and hence it does not in general admit of application in the case of snow, which is relatively opaque to both light and heat. Therefore, this cause of separation cannot be invoked in the case of the growing ice-sheet of the Glacial Period, since it was a necessary condition of its formation that the winter snows remained unmelted upon its surface, accumulating thus to a great thickness and slowly changing downward through *névé* to glacial ice. We must suppose, then, that from the top of the ice-sheet to the lower limit of frost in the soil was one solid mass — ice above and ice and soil below.

It may safely be assumed that over the glaciated area in preglacial times, as now in lower latitudes, the superficial detritus or soil was chiefly the residuary product of quiet chemical decay. This is equivalent to saying that it consisted chiefly of clay and sand. Hard, angular fragments of rock, such as are so common in the till, were wanting, and the rounded, bowlder-like nuclei of decomposition must have been of rather rare occurrence at points near the surface of the ground or above the lower limit of the frost.

If we may assume a thickness of residuary detritus commensurate with that which now mantles the Southern States, it is, perhaps, probable that over considerable areas solidification by freezing would fail to reach the firm, undecomposed rocks beneath. However that may be, it is certain that with increased thickness the ice-sheet became a more and more efficient protection to the ground against the climate of the Ice Age, and the steady efflux of heat from the earth's interior would

thus tend to gradually loosen the hold of the frost upon the rocky substratum.

Observations in the arctic regions and at high altitudes show that the ground may become frozen to a depth of several hundred feet, and R. S. Woodward's theoretical discussion[1] of the subject not only corroborates these observations, but indicates that the downward penetration of the frost may be comparatively rapid. Thus if the mean annual temperature of the surface should fall from 60° F. to 10° F., the ground would become frozen to a depth of 400 feet in less than one thousand years. Russell suggests[2] that the great depth of frozen soil reported at Yakutsk, Siberia (382 feet), and at other arctic stations, may be due in part to the surface accumulation of ice through the growth of the tundra, and that possibly the rate of diffusivity of temperature assumed by Woodward is too high, but he does not seriously question the main conclusion with regard to the efficiency of frost penetration.

It is well known that glaciated areas are not in general those of most extreme cold. A humid climate is the first essential; and, given that, a temperature low enough throughout the year to insure precipitation chiefly in the form of snow and to prevent excessive waste by summer melting — a mean annual temperature a few degrees only below freezing, like that on the Mount St. Elias coast of Alaska — is all that is required for active glaciation. In harmony with this conclusion, we find that the extremely frigid areas, such as the interior of Alaska and northern Siberia, are relatively dry and non-glaciated. For this reason, and also because the increasing thickness of a sedentary ice-sheet would tend to neutralize the downward penetration of frost, we need not suppose that the ground beneath the ice would be frozen to any great depth or far below the detrital layer.

The relatively high conductivity and diffusivity of pure ice, in comparison with the covering of *névé* and snow, would tend, through the steady efflux of the terrestrial heat, to raise the temperature of the lower portion of the ice-sheet to the melting point. On the other hand, the high latent heat of fusion would tend to prevent extensive melting of the ice until the entire basal portion of the sheet had attained approximately the melting temperature. The effect of the

[1] Bull. Geol. Soc. of America, 1, 130–132.

[2] Ibid.

weight of the ice itself in lowering the temperature of fusion of its base would be too small to require consideration here.

The interesting question now arises as to the most probable plane of shearing when the sedentary ice-sheet finally begins to move. We may assume that the initial basal shearing or gliding plane will be approximately the same whether the ice-sheet begins to move in obedience to its own weight or through the overriding thrust of a thicker northern sheet. In any case, or whatever the cause of movement, it is, as we have seen, most likely to be inaugurated during a period of climatic amelioration. Above the bed-rock, three layers of material require consideration: (1) The ice-sheet proper; (2) the frozen soil beneath it, to which it is still firmly united; (3) the unfrozen soil resting upon or passing downward into the solid rocks. Under the assumed conditions of climatic amelioration and a basal rise of temperature in the ice-sheet, we may suppose that the frozen soil, in consequence of its lower position and the relatively low specific heat of earthy and stony substances, would tend to rise in temperature and to thaw earlier than the pure ice. Hence the frozen soil may, perhaps, be regarded as weaker and more susceptible of shearing than the clear ice, although at temperatures well below freezing the reverse relation would probably hold true. We thus arrive at the conclusion that at the inception of movement in any part of the ice-sheet the ice is possibly stronger than, but essentially continuous with, the frozen soil, and the latter is clearly stronger than the unfrozen soil; and hence it would follow that the most probable initial plane of slipping or shearing would be in the unfrozen soil, the frozen soil and overlying ice moving *en masse*, and the movement being lubricated by the unfrozen soil, which would be at most points of an argillaceous and plastic character. Although a residuary soil naturally becomes firmer and more rock-like downward, and is, therefore, weakest near the surface, we should not lose sight of the fact that, since frost causes a notable expansion of the soil, a recession of the lower limit of the frost toward the surface, through the efflux of the terrestrial heat and consequent rising of the isogeotherms, would tend to leave at the lower surface of the frozen soil a thawed-out layer of loose and yielding texture.

Observations heretofore made on modern glaciers and ice-sheets are of little value in this connection, because nowhere in the field of observation are realized the conditions that must obtain at the base

of a sedentary or recently sedentary ice-sheet. The true glaciers or ice rivers of Alpine districts, Greenland, etc., are mere lobes of ice descending under the influence of gravity from the edges of *névé* fields and ice-caps into a climatic zone where permanent ice cannot form; and hence they are moving over unfrozen soil, and the ice is wasting by melting on its under as well as its upper surfaces. The great *desideratum* is, evidently, a shaft or boring in the interior of Greenland extending through the entire thickness of the ice-sheet and a hundred feet into its rocky bed. This would expose the true basal relations, thermal and otherwise.

In his recent paper on the "Influence of Débris on the Flow of Glaciers,"[1] Professor Russell assumes that ice is analogous to pitch in that its plasticity or tendency to flow is diminished by inclosed *débris*. This assumption is undoubtedly safe for temperatures well below freezing. But if it is a sound principle that when the temperature of the ice is rising and near the melting point the inclosed rock *débris* will, on account of its lower specific heat, tend to rise in temperature faster than the ice and thus to loosen by melting the bonds between it and the ice, then the comparison with *débris* in pitch would seem to hold good only in the improbable case when the imbedded stones caused a local softening of the pitch. The *débris* in ice would not lead to extensive melting, on account of the high latent heat of melting ice. But if the temperature of the *débris* rises ever so little above 0° C. (32° F.), it ceases to be a source of strength in the ice, the effective section of the ice being diminished in proportion to the amount of *débris*. This view seems to be abundantly confirmed by Professor Chamberlin's Greenland studies, for he has given us no more striking and significant fact than the relative facility with which the ice shears along innumerable lines of *débris;* and the evidence is conclusive that the ice, to a large extent, slides over the inclosed *débris*, instead of dragging it along, as it would if the *débris* were firmly frozen into the ice. Granting, however, that the frozen soil would be more rigid and indifferent to gravitative stresses than the clear ice above it, the fact remains that the unfrozen soil at the base is more yielding and plastic than either; and hence, although we may reasonably conceive definite shearing planes as distributed through a considerable thickness of the ice-sheet, the lowest plane, and the true base of the ice-sheet, will still be at the lower limit of frost.

[1] Journal of Geology, 3, 823–832.

So far as I can learn, everywhere within the range of observation modern glaciers are either sliding over their ground moraines or they rest directly upon the firm bed-rock, just as many rivers, at ordinary seasons, flow quietly over deep beds of gravel and stones or over bare ledges. In both cases active erosion of the bed-rock floor is nearly at a standstill, for where it is not protected by the stagnant *débris* the ice or water are not well suppled with stones, without which they can do little. In the case of the river, periods of flood or of greater fall or volume in the past must be postulated to set the detritus in motion and account for the effective erosion of their channels. Similarly for the glacier, the entire ground moraine must be set in motion. Increased thickness and velocity of the ice would probably tend to accomplish this. But to my mind rectilinear striæ, often scores of feet in length, are an impossibility unless we conceive the entire mass of the ground moraine as inclosed in the moving ice.

Professor Chamberlin's observations in Greenland show that any number of horizontal shearing planes may be postulated, with a corresponding reduction of the basal velocity; but I see, with Upham, no escape from the conclusion that during the period of active and efficient glaciation of the bed-rock surfaces the ground moraine was very scanty or wholly wanting, being incorporated with the moving ice. Imagine a modern glacier or ice-sheet as launched upon a plain covered by 25 to 50 feet of sedentary detritus passing gradually downward into firm rocks, and consider how little chance there would be for the development on the underlying bed-rock of a typical glaciated surface so long as the ice and soil are essentially distinct. The preliminary removal of the detritus by simple thrust and drag is seen not to be a valid explanation when we consider the great breadth of the glaciated area and the enormous marginal accumulation which would inevitably result. A true ground moraine between bed-rock and ice, and distinct from both, belongs to the waning stage of the ice-sheet and to lobes of ice (glaciers) descending from an ice-cap or *névé* field into a climatic zone where permanent ice cannot form.

All this appears to be quite consistent with the local origin of the greater part of the till or ground moraine of the Pleistocene ice-sheet and the well-established fact that the total movement of the ice amounted to hundreds of miles if we simply suppose that through the granular plasticity of the ice, or a series of shear planes, the basal, drift-laden layer moves much more slowly than the overlying clear ice.

Absorption of Drift by the Pleistocene Ice-sheet.

Glacialists are sharply divided in opinion as to the power of an ice-sheet to absorb or incorporate with its mass the detritus over which it moves, and the arguments *pro* and *con* have been stated with much fullness and force in recent papers by Upham, Chamberlin, and others.[1] It is clearly incumbent upon the advocate of the englacial theory to prove that large volumes of drift may become englacial. It seems to me that this has not been satisfactorily done as yet, and, as previously stated, the chief purpose of this paper is, if possible, to reinforce the englacial theory at this point.

The sedentary ice-sheet, as we have seen, holds in its grasp a large part of the surface detritus; and if, as I believe, the initial shearing plane is normally or usually at the lower limit of frost, a considerable body of detritus, mostly of a fine or impalpable character (preglacial residuary soil, etc.), is englacial from the beginning of movement of the ice-sheet. When a sedentary ice-sheet is overridden by a piedmont glacier, and still more when a sedentary ice-sheet is overridden by the re-advance of an earlier ice-sheet, the conditions must be favorable for the transfer of drift from the base of the earlier sheet to a somewhat elevated position in the composite sheet which results from the overriding. We may suppose that the overriding sheet will carry with it not only its own englacial drift, but will drag along, also, a part of its ground moraine or subglacial drift. This complex process will be repeated with each marked recession and re-advance of the ice-sheet.

It is altogether probable that each important recession of the ice-sheet, and not alone the final recession, was characterized by numerous glacial rivers and lakes and an extensive development of modified drift in the well-known forms of kames, eskers, deltas with abrupt northern margins, etc. It is obvious that such eminently loose and porous deposits would be completely permeated by and form an essential part of the succeeding sedentary ice-sheet. Thus material which may have slowly become englacial through the movement of an earlier ice-sheet is englacial from the beginning of the succeeding sheet; or, if the later ice should move over these deposits, their forms and structures are very favorable to their being absorbed by the ice through shearing and flexing.

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[1] Upham has recently cited all the more important of the later contributions to this discussion. Bull. Geol. Soc. Amer., 5, 72, 73.

Some of the illustrations accompanying Professor Chamberlin's valuable description of the Greenland glaciers[1] are well calculated to dispel any doubts that may exist in the minds of geologists as to the power of a glacier to absorb detritus by shearing and flexing movements. The flexures are certainly very remarkable, considering that, strictly speaking, ice is neither viscous nor plastic. Chamberlin's explanation of movement as the result of granulation and a continuous adjustment of the granular structure to gravitative stresses through differential melting and regelation obviates in a measure the difficulty of accounting for the complex movements observed; but the fact remains that relatively slight obstructions, whether of solid rock or uncompacted drift, are sufficient to originate sharp overthrust flexures and obliquely ascending shear planes, which are marked by prominent bands of *débris* — ground moraine in process of absorption by the ice. To Chamberlin belongs the credit of observing and depicting more clearly, perhaps, than any previous writer the mechanism of the transfer of drift from a subglacial to an englacial position. There can be no doubt now that in a lee the ice, at least under certain conditions, will drag, in consequence of basal friction, sufficiently to give rise to a sharp flexure or a thrust fault between it and the ice which passes over the obstruction. A part of the latter is being constantly curved downward and backward and added to the stagnant ice, and thus the thickness of the latter increases with the distance from the lee slope, and the axial plane of the flexure rises to higher levels in the ice; or, if the conditions of granulation, velocity, etc., determine shearing as well as or instead of flexing, the shearing plane will likewise tend to rise in the ice.

In an earlier publication[2] Professor Chamberlin has analyzed glacial motion and shown the importance, in a detailed study, of distinguishing vertical pressure, due to the thickness and weight of the ice, and flowage pressure, due to its horizontal movement. The former culminates in the basal central and the latter, as a rule, in the superficial peripheral tracts. These two pressures coöperate on stoss slopes, and hence glacial erosion reaches its maximum intensity there. Glacial striæ record, almost exclusively, the movements of the ice-sheet in its final stages, and it is well understood that the general absence of

[1] Journal of Geology, 3, 478, Figs. 28–30, Bull. Geol. Soc. Amer., 6, 203–214, plates 5–9.

[2] Seventh Ann. Report, U. S. Geol. Surv., 186–192.

striæ on lee slopes above a certain low angle of declivity means that the flowage pressure then so far predominated over the vertical pressure that the ice tended to arch over the lee slope instead of flowing down it. Under the greater vertical pressure and lower velocity of the central areas the ice will hug the lee slopes more closely, and they will be more generally glaciated. In this case, however, as truly as in the first, the ice in the lee must drag — that is, move more slowly than the ice above it; and this retardation will almost inevitably, according to Chamberlin's Greenland observations, lead to flexing or shearing and the absorption of detritus. We are thus brought to the conclusion that from the summit or crest of nearly every elevation with an abrupt lee slope a stream of detritus flowed onward and upward into the Pleistocene ice-sheet during its progress over the land. And it is obvious that, if this view be even measurably sound, the mechanism is provided for the abundant transfer of drift from a subglacial to an englacial position. This important conclusion may be presented in another way. The detritus urged up or worn from the stoss slopes by the movement of the ice clearly did not descend the lee slopes under the pressure of the ice, else these slopes would not be unglaciated; therefore it must have passed on into the ice, or else have accumulated in a passive form on the lee slopes. It was probably disposed of in both these ways, but it is well known that stoss slopes are quite as likely as lee slopes to be encumbered by ground moraine.

The recently published experiments in ice motion made with wax by E. C. Case[1] have a special interest in this connection. They tally very closely with Chamberlin's Greenland observations, and materially strengthen our general conclusion that the forward motion of the ice over an uneven topography gives rise to obliquely ascending currents and that from the summits of elevations basal detritus is carried, not down the lee slopes, but forward and upward into the body of the ice.

It must, however, be conceded by the englacialist that during the period of maximum glaciation for any area, when the ice was thickest and the vertical pressure had its maximum value, a large proportion of the drift reaching the top of stoss slopes probably remained in the bottom of the ice and was dragged down the lee slopes and away from the elevations without losing its subglacial position. This must have involved the striation and polishing of the lee slopes, and the condi-

[1] Journal of Geology, 3, 918–934.

tions were unfavorable for the detachment of blocks of rock — the rending and quarrying operations of the ice-sheet. Later, when the vertical pressure was less and the velocity of flow greater, the ice hugged the lee slopes less closely, and the conditions became favorable for the detachment of blocks by the ice moving under the combined vertical and flowage pressure across the crests of the elevations. If the ice actually pulled away from the lee slopes to an appreciable extent, or even tended to do so, the local relief of pressure may, perhaps, have led to the freezing on these slopes of subglacial water. This sedentary ice, penetrating the joint cracks of the rocks and by its expansive power starting the joint blocks from their positions, and later, by its continued growth, becoming continuous with the moving ice, may have assisted in plucking away blocks and fragments of rock from the lower as well as the upper portions of the lee slopes, thus tending to maintain the high angle of declivity so characteristic of lee slopes.

The broken and precipitous character of typical lee slopes is, to my mind, rather inconsistent with the passage down them, during the detachment and removal of the blocks, of much ground moraine; and this conclusion is in harmony with the facts that they are not now, as a rule, banked high with till and that we often find a surface train of angular blocks leading away from them. That the blocks thus borne away from a lee slope were, in many cases, carried in the ice instead of being dragged along beneath it is proved by the occurrence of entirely angular and unglaciated forms and the fact that, as in the case of the great Madison bowlder in New Hampshire, the original orientation of the blocks is sometimes unchanged.[1]

In the preceding paragraph I have but followed in the footsteps of Professor Chamberlin, for he has shown[2] very fully and clearly that the ice flowing over and around prominent ledges and rocky hills will naturally carry away in true englacial fashion many angular blocks and more or less of other forms of detritus, and also that this, as he supposes, scanty englacial drift is now distinguishable from the ground moraine on which it rests. Having granted this much, Professor Chamberlin is, apparently, obliged to ground his argument for the essential scantiness of the englacial drift upon the assumption,

[1] Appalachia, 6, 66.

[2] Journal of Geology, 1, 47–60 and 255–267.

nowhere explicitly stated, that but little drift was dragged or carried by the ice up the stoss slopes and over the crests of the ledges and hills, for this material would obviously have an equal or better chance than that worn from these elevations of becoming truly englacial. But the validity of this tacit assumption cannot be admitted. The severe glaciation of the stoss slopes is against it; and, aside from this consideration, it is difficult to understand how, except in valleys trending with the glacial movement, any considerable amount of detritus that was transported or dragged a good fraction of a mile or more from its source could help crossing one or more elevations. Certainly its course would need to be very devious to avoid them.

Again, Professor Chamberlin[1] has given us the important principle that, during the closing stages of the Ice Age at least, the surface of the ice-sheet must have been depressed over highlands and elevated over valleys, and that, movement being determined by surface gradient alone, the ice would flow toward rather than from the highlands. This principle would thus operate to increase the ground moraine on the hilly tracts at the expense of that in the valleys and lowlands; and it has occurred to me that perhaps we have here an explanation of the long, ridgelike accumulations of till which often, on the plain country, border or separate the north-south valleys. Just as a river does not make its chief deposits in the deepest part of its channel, where the current is strongest, but along the margin, building up the flood plain, so the ice stream tends to crowd the detritus out of north-south valleys from the line of swiftest to the lines of slowest motion. From these till ridges we pass easily and naturally to drumlins. Every glacialist knows that the drumloid slopes of till, which may, in my opinion, be regarded as embryo drumlins, although most characteristic of stoss slopes, occur abundantly on lee slopes also. They seem to indicate an attempt on the part of the ice-sheet to carry or drag a large amount of drift up the stoss slopes. When the drift gains the crest it is in part carried away into the body of the ice by the freer motion of the ice above this level, tending to leave the lee slopes bare, as already noted. But during the waning of the ice-sheet its movement over the rock hills and ledges finally became so feeble that it could no longer urge all the subglacial drift, the amount of which was probably being augmented by basal melting, up the stoss

[1] Seventh Ann. Report U. S. Geol. Surv., 184, 185.

slopes, and it began to accumulate upon them. Each increment was so thoroughly compacted and pressed down by the ice, aided by the natural tenacity of the clay, that the effective stoss slope was gradually raised until the accumulation of till finally overtopped the rocky obstruction and became a drumlin. This view seems to be in entire accord with Professor Chamberlin's recent suggestion with regard to the origin of drumlins.[1]

Perhaps the general conclusions to which my studies have now led me may be best stated as follows: A large part, probably the main part, of the preglacial surface detritus was englacial in the sedentary ice-sheet and remained so after the ice began to flow during the entire period of the growth, culmination, and early decline of the ice-sheet, or while the hard bed-rock surface was being actively abraded and striated. During this time, which embraced the greater part of the Glacial Period, the preglacial detritus not originally incorporated in the ice and the material worn from the ledges by the ice itself became englacial, in large part at least, through overriding, shearing, and flexing movements of the ice, a hard surface of drift-shod ice in direct contact with the uneven bed-rock surface appearing to be essential to the rectilinear striation of the latter. During the later stages of the decline of the ice-sheet basal melting set free considerable volumes of the hitherto englacial drift to form the ground moraine; and just as the frontal or terminal moraine, also composed of material set free by the ablation of the ice, records the cessation of the forward movement or invasion of the ice-sheet, so the basal or ground moraine records the gradual cessation of the glacial abrasion of the bed-rocks. The relative suddenness of this change from active erosion to deposition in any area is indicated by the fact that, generally speaking, the ground moraine rests everywhere upon normally striated surfaces. In other words, as soon as the ground moraine began to appear through basal melting it was essentially motionless, for ice moving over a bed of detritus in a way to impart motion to it would inevitably give rise to sidewise, oblique, and devious movements of individual stones which would tend to obscure and efface the rectilinear striation of the bed-rock surface. The ground moraine as it accumulated was pressed down by the ice to form the typical hardpan. In part it accumulated on stoss slopes through obstruction to, and in part on lee slopes

[1] Journal of Geology, 3, 480.

through protection from, the forward movement of the ice, forming drumloid slopes and, later, drumlins.

It is not a necessary deduction from this view that the bed-rock always rises to a good height in drumlins, since the hardpan character of the ground moraine and the tendency of the ice at this stage to flow over loose materials, as observed by Niles, Spencer, Chamberlin, and many others, make of the initial knob or boss of the ground moraine an efficient gathering point for more material as fast as it is furnished by the melting of the ice. The main point may be presented in another way. When, as in the earlier and maximum stages of the ice-sheet, the basal temperature was below freezing, the freezing of subglacial waters made and kept the detritus a part of the ice-sheet; and when, as in the later stages of the ice-sheet, the basal temperature rose above freezing, the ice relaxed its hold on the detritus and flowed over it, as attested by observations on modern glaciers.

It is a necessary consequence or corollary of this view that transportation of drift by simple drag is relatively unimportant, if not impossible. The transportation is almost wholly englacial, as insisted by Upham,[1] but highly differential, being extremely slow in the basal layers and more and more rapid at higher levels. The detritus reaching the highest levels in the ice is carried farthest, not only because of the higher velocity, but also because it remains for a longer time in the ice.

The history of an ice-sheet embraces, as regards the basal temperature, two distinct and contrasted periods: (1) The period of growth and maximum development, when the temperature of the lower part of the ice is permanently below freezing; (2) the period of decline, when the basal temperature is above freezing. The first is the period of active abrasion and scoring of the bed-rock, all detritus being frozen into the ice as fast as formed. Furthermore, the water resulting from superficial summer melting of the ice, descending through crevasses to the basal portion of the sheet and refreezing there, not only adds the newly formed detritus to the base of the moving sheet, but also, perhaps, favors an actual downward growth of the ice-sheet, whereby detritus which has previously become englacial is raised to greater heights in the ice, the growth of the ice-sheet being chiefly upward by snowfall in winter and downward by basal freezing in summer.

[1] Bull. Geol. Soc. Amer., **6**, 348.

During the second period the ice-sheet wastes by basal as well as superficial melting, the englacial drift becomes subglacial (ground moraine), and glacial erosion gradually ceases.

The prevailing opinion among geologists, as recently collated by Culver,[1] is evidently strongly against the efficiency of glacial erosion, and this trend of opinion is certainly justified so far as it is based upon observations on living glaciers. Observations on the velocity and abrasive power of modern ice-sheets have never been made. But the relatively high efficiency of the Pleistocene ice-sheet in this respect is clearly proved by the undisputed facts that over practically the entire glaciated area north of the terminal moraine *all* the preglacial sedentary soil and partially decayed rock were worn away, involving on a large aggregate area extensive erosion of the hard, unaltered rocks, and that the prevailing color of the ground moraine below the sharply defined limit of postglacial oxidation is that of crushed rock, and not of residuary or other preglacial detritus. The latter fact, which seems to have been but little regarded, is probably of equal significance with the first, and the general conclusion based upon both these is further sustained by observations upon the proportions of distinctively glacial detritus in the ground moraine.[2] It is a logical deduction from the view developed here that there can exist in the ground moraine, in general, no real or definite distinction between subglacial and englacial till, because, broadly speaking, it has all been englacial.

Probably no feature of the Greenland glaciers revealed to us by Chamberlin's studies will be regarded by glacialists with greater interest and astonishment than the beautiful stratification and lamination of the ice. He states, and his photographic illustrations show, that the stratification is most perfect in the lower, drift-laden portion of the ice, being only obscurely seen in the upper white ice. It is especially interesting to note in this connection that in the drift-laden ice the stratification is due chiefly to the mode of distribution of the drift or rock *débris*, which forms numerous relatively thin and continuous layers approximately parallel with the bottom of the glacier and often exhibiting flexures and faults where the ground over which the glacier moves is sufficiently uneven. Chamberlin refers all this englacial drift

[1] Trans. Wis. Acad. Sci., etc., 10, 339–366.

[2] Proc. Boston Society of Natural History, 25, 131–138.

to one source. It is ground moraine which has been absorbed by the ice through flexing and shearing movements, and it proves that this process of absorption is essentially continuous. The thinness and persistence of the layers of *débris* also prove that the planes of shearing extend forward indefinitely into the body of the ice, and do not tend to die out, as they would if the ice were a viscous or plastic substance. This differential movement along an inset layer of *débris* must drag it out and tend to give it persistence, even if the process of absorption in that plane is intermittent.

Furthermore, we find here a most striking confirmation of the conclusion previously stated, that, under certain conditions at least, the *débris* in the ice is an element of weakness and tends to give rise to shearing and gliding planes. This whole process of lamination by shearing is beautifully attested by the marked projection of the upper layers on the precipitous margin of the ice due to ablation. The under surfaces of the projecting layers are fluted by the fragments of rock lying in the plane of shearing. But in spite of this indication that the ice moves over the inclosed detritus, it is obvious that the movement must also drag it along; and when we consider how intimate this process of lamination shearing is, producing in extreme cases as many as twenty distinct layers in an inch, it can hardly be doubted that the englacial rock fragments, more especially if of small size, must suffer faceting and striation after the manner of the ground moraine. Thus one supposed distinction between subglacial and englacial drift in a measure disappears, and is no longer available as an argument to minimize the englacial drift of the Pleistocene ice-sheet.

Professor Chamberlin has noted[1] that while the Greenland glaciers commonly slide over the ground moraine in their lower courses, allowing it to accumulate beneath them, they appear in their upper courses to drag and carry it along, fitting snugly in their respective valleys and scoring the ledges over which they move. By parity of reasoning we may suppose that, although at its lower extremity the ice is observed to slide over the interstratified *débris*, farther back from the margin the *débris*, being frozen in the ice, is urged along and glaciated by the motion of the ice.

I have observed something analogous to this lamination shearing of

[1] Journal of Geology, 3, 67 and 208–210.

glacial ice in the obsidian flows of the Lipari Islands. In consequence, perhaps, of incipient crystallization, or of partial relief from pressure, due to the fact that the lava continued to flow after it had begun to stiffen, imprisoned or dissolved aqueous vapor is liberated along certain planes coincident with the plane of flowing, giving rise to layers of vesicles. These vesicular layers (analogous to *débris* layers in the glacier) become, with continued stiffening of the magma, relatively planes of weakness and hence shear planes — a true flowing movement which affects the entire body of magma being transformed in part, by continued pressure from behind, to mechanical shearing along definite planes.

Comparison with Modern Glaciers and Ice-sheets.

Perhaps the most cogent argument against the view that the drift of the Pleistocene ice-sheet was, during certain prolonged phases of its history, largely or chiefly englacial is that based upon the comparative rarity of englacial drift in modern glaciers and, seemingly, in modern ice-sheets. The general freedom of glaciers of the Alpine type from incorporated drift, other than that derived from lateral and medial moraines through the agency of crevasses, is, no doubt, attributable to the facts that their courses were long since swept relatively bare of detritus and that in their lower courses they are undergoing basal melting, and hence depositing rather than absorbing drift.

According to the observations of Chamberlin and Salisbury,[1] the numerous glaciers descending from the margin of the Greenland ice-cap present, in this respect, two types: (1) The drift-laden glaciers, which have commonly vertical sides and ends and predominate north of latitude 76°; (2) the apparently drift-free glaciers, which are commonly without prominent vertical sides or ends and predominate south of latitude 76°. Both these able observers state emphatically that in the drift-laden glaciers the drift is strictly a basal feature, rarely rising to greater heights in the ice than 100 to 150 feet even where the glacier may be a thousand feet or more in thickness. Furthermore, these observations are regarded as fully confirmed by those made upon the countless icebergs of the neighboring seas. We may, perhaps, reasonably suppose that the greater abruptness of the northern glaciers is due in some measure to the more rapid melting of the drift-

[1] Journal of Geology, 3, 875-902.

laden basal layers of the ice, in consequence, as already explained, of the low specific heat of the imbedded *débris*, and that, possibly, the northern glaciers are more generally drift-laden because the severe climate tends to prevent basal melting. Certain it is that the englacial drift is, in general, most in evidence where the basal conditions most closely approximate those of an ice-sheet in its prime.

It appears to me, however, extremely improbable that all the englacial drift of the Greenland glaciers has been absorbed by the ice during its comparatively short and steep descent from the margin of the ice-cap. I would suggest instead that a considerable part of it represents the lower, drift-laden portion of the ice-cap itself. Whether these lobes of the ice-cap are well charged with drift or not is of no special significance in a study of the Pleistocene ice-sheet of North America, unless we can regard them as reliable indications in this respect of the constitution of the parent ice-cap. Assuming with Chamberlin that, while the upper, clear ice of the Greenland glaciers increases rapidly in thickness from the lower end upward toward the ice-cap, the basal, drift-laden ice increases but little if any in thickness, is it a necessary conclusion that in the ice-cap itself, thousands of feet in thickness, the englacial drift is limited to the lower 100 to 200 feet? To answer in the affirmative is to lose sight of the principle that the velocity of the ice increases rapidly upward from the bottom. The ice-cap virtually spills over the edge of the plateau through deep V-shaped notches; and to my mind the conclusion is unavoidable that a much larger proportion of the upper, clear, and relatively mobile ice will flow down than of the lower, drift-laden, and relatively immobile ice. It is probable that increased declivity would in any case accelerate the velocity of the upper more than of the lower layers of ice, but this contrast would certainly be greatly intensified by the section of the valley — broad and open above, and narrow below.

It is the general belief of geologists that if Greenland were divested of its ice-cap it would exhibit continental relief — elevated margins and a depressed interior. Hence we may assume that the ice-cap attains its maximum thickness in the central areas, and that a smothered mountain range separates this main body of ice from the overflow fringe of glaciers along the coast. The futility of regarding these smaller coastal glaciers as representative, in the matter of englacial drift, of the great ice-cap from the marginal and superficial portions of which they originate is obvious.

The Humboldt glacier and others of the great glaciers of the Greenland coast belong in quite a different category, occupying as they do, apparently, the lower courses and mouths of the great interior valleys; but, terminating in the sea, we can only judge of their basal conditions by the icebergs to which they give rise. It is, perhaps, fair to assume that, through basal melting, these giant glaciers, like their smaller brothers which fail to reach the sea, are building platforms of the ground moraine beneath their extremities and thus permanently shallowing or filling up the bays along the coast. But that the icebergs often carry away generous loads of drift is well known, and we may specially note in this connection (1) that perhaps many of what pass for small bergs are really large bergs deeply laden; (2) that bergs well ballasted with drift cannot possibly be overturned so as to expose the drift to observation; and (3) that the drift-bearing part of a berg, under the combined influence of the higher specific heat of rocky *débris* and gravitation, must melt away very rapidly when the temperature of the water is above freezing. Again, these giant glaciers are simply ice rivers draining at lower levels the great *mer de glace* or interior sea of ice; and, just as in the case of the water of a lake and its outlet stream, the velocity of the ice must be greatly accelerated in passing from the *mer de glace* to the glacier. From this premise the conclusion follows irresistibly, as previously noted, that the glacier will consist in much larger proportion than the *mer de glace* of the upper, drift-free ice. Hence we can hardly suppose that even a clearly exposed section of the Humboldt glacier would reveal to us a true and undistorted vertical section of the Greenland ice-cap, for the basal layers certainly would not be adequately represented. Thus observation is baffled at every point, unless, indeed, a boring should some time be made in the interior of Greenland. I see no reason, however, to doubt that the *mer de glace* is well supplied with englacial drift, or that wherever the ice is actively abrading its bed it holds in its mass the entire volume of detritus, moving, full armed and without any intervening shield or ground moraine, over the unprotected bed-rock.

That the englacial drift rises to a great proportional height in the Greenland or any other ice-cap appears to me, however, by no means a necessary conclusion. Probably very little rises to a greater height than 500 feet, or possibly 1,000 feet, even where the thickness of the ice is one to two miles. In fact, none of the suggested processes of

absorption seem competent to diffuse the detritus through any considerable thickness of the ice, or to carry it far above the summits of the obstructions which give rise to the shearing and flexing movements. I conceive it, rather, to be somewhat crowded in the slow-moving basal strata of ice, whence it is early set free by basal melting to form the ground moraine, and to thin out rapidly upward. Among the causes tending especially to check or limit the upward movement of drift in the ice is the progressive increase in the velocity of the ice from the base upward, in obedience to the principle, already noted, that a current tends to force floating bodies from the lines of highest velocity to those of lowest velocity.

It is possible, however, that, as virtually pointed out by Upham,[1] an important exception to this limitation of the range of englacial drift should be made for the case when a later sedentary ice-sheet is overridden by the re-advance of an earlier sheet, the height attained by the englacial drift depending then upon the thickness of the overridden sheet. Again, a mountainous tract lying in the pathway of the ice-sheet may lead to the incorporation of drift at exceptionally high levels. In fact, the Malaspina glacier is a capital example. According to Russell, the drift which mantles the outer margin of this great piedmont glacier covers, even in parts of the area where it is forest-clad, not less than a thousand feet in thickness of ice, and where it is not forest-clad it rises to still greater heights. Russell states that this superglacial drift consists wholly of the lateral and medial moraines of the tributary glaciers descending from the Mount St. Elias range.

"All of the glaciers which feed the great piedmont ice-sheet are above the snow line, and the *débris* they carry only appears at the surface after the ice descends to the region where the annual waste is in excess of the annual supply. The stones and dirt previously contained in the glacier are then concentrated at the surface, owing to the melting of the ice. This is the history of all the moraines on the glacier. They are formed of the *débris* brought out of the mountains by the tributary Alpine glaciers and concentrated at the surface by reason of the melting of the ice."

Probably this incorporation of drift at high levels would still occur, but on a grander scale, if the St. Elias range were completely buried in ice moving across it. Regarding these St. Elias glaciers as rivers

[1] Bull. Geol. Soc. Amer., 7, 21, 22.

of ice tributary to a sea of ice, the thought is naturally suggested that perhaps the drift-laden ice tends, on joining the piedmont glacier, to flow out across the ice sea regardless of its depth, and thus, while actually descending topographically, rise to greater heights in the ice-sheet. This principle would also, obviously, find application in the case of valleys or depressed areas of any form transverse to the general direction of flow of the ice-sheet, and it thus becomes simply a broader phase of the principle of the absorption of detritus by shearing and flexing. These considerations lead me to venture the opinion that, while depths of englacial drift amounting to 1,500 or 2,000 feet or more, or to one fourth to one third of the thickness of the ice-sheet at its maximum, as held by Upham, cannot be regarded as strictly normal or as prevailing over considerable areas of plain country, they are possible under the special conditions indicated.

Relations of Englacial Drift to Modified Drift.

The manifold forms of modified drift, or washed and stratified gravels, sands, and clays, of glacial origin, forming deltas, terraces, overwash or apron plains, eskers, kames, etc., although occurring almost wholly in valleys and on lowlands, constitute in the aggregate a considerable fraction of the total volume of the drift. Concerning the source of the modified drift, there is as yet no general agreement among glacialists. The main views, of which all others may be regarded as modifications, are (1) that the modified drift has resulted chiefly from the washing and assorting of the till or ground moraine by glacial streams during and following the waning and disappearance of the ice-sheet, (2) that it was derived from englacial drift through the agency of subglacial streams, and (3) that it had its origin in englacial drift which became superglacial by ablation and was washed and assorted by superglacial streams. Undoubtedly all of these theories are required to account for the totality of the modified drift, and the real question is as to their relative importance.

It is inconceivable that the ice-sheet could disappear without some washing or modification of the ground moraine. It is, however, a noteworthy fact that the till does not present about the heads of southward sloping valleys or elsewhere evidences of such extensive erosion as should be required for the general or unqualified accept-

ance of this view. The absence, as a rule, of strongly marked erosion lines in the ground moraine is particularly striking in the case of the drumlins, since their highly definite and characteristic contours due to glacial molding make them extremely delicate records of aqueous erosion. Every glacialist knows how rare and insignificant are the evidences of drumlin erosion which can be referred to subglacial streams. Superglacial and marginal streams have here and there notched the summits or terraced the sides of protruding drumlins, and frost and rain-wash doubtless accomplished some degradation of the drumlins after the disappearance of the ice and before the mat of vegetation was spread over them. But when all these modes of erosion are taken into account, the waste which drumlins have suffered still appears so trifling that, if they were regarded as representative in this respect of the ground moraine in general, all subglacial material might, perhaps, be safely neglected as a source of modified drift. In fact, the advocates of the derivation of the modified drift from the ground moraine should, it would seem, also espouse the theory that drumlins are mere erosion remnants of a sheet of till of much greater average thickness than that which now encumbers the glaciated area.

It may be noted, however, that, as I have elsewhere pointed out,[1] the ice-sheet was probably accompanied, at least in its later stages, by a more or less complete system of subglacial drainage; and during all the time while the ground moraine or subglacial till was accumulating through basal melting, and also while it was still englacial, through the agency of numberless shearing planes, it was undergoing modification by the washing out of its finer constituents, clay and rock flour. Obviously, of this differential erosion no distinct trace or scar could be expected to survive the disappearance of the ice-sheet, especially since the action could not have been sharply localized, but must have affected in some degree almost the entire area of the ground moraine.

While not denying or doubting that the ground moraine has made, in various ways, substantial contributions to the modified drift, I recognize that the relations of the still englacial drift to glacial drainage afford a more direct and satisfactory explanation of the main part of the modified drift.

The real problem appears, then, to be as to the relative efficiency of subglacial and superglacial streams. Upham, the foremost advocate

[1] Proc. Boston Society of Natural History, 25, 117.

of the efficiency and sufficiency of superglacial streams, holds that the englacial drift became superglacial, by surface ablation of the ice, in sufficient volume to account for practically all the various types of modified drift, and that the superglacial streams were adequate for its transportation and deposition. That this must be the history of a part of the modified drift is obvious from the fact that these conditions are realized in modern ice-sheets, but they are only realized, it must be added, to a very limited extent.

It is a common and, perhaps, a fair assumption that in Greenland and Alaska are exhibited now, on a smaller scale, nearly all the essential phases of the disappearance of the Pleistocene ice sheet. A general survey of these and other regions now undergoing glaciation has revealed only one notable occurrence of superglacial drift, namely, that mantling the outer margin of the Malaspina glacier; and that, as we have noted, is of somewhat exceptional origin, inasmuch as it is not derived from strictly normal englacial drift. Little more can be said for superglacial streams. They are either entirely wanting or they are short-lived, being almost invariably swallowed up by crevasses and rarely discharging over the margins of the ice-sheets. Nowhere, so far as I am aware, have superglacial streams been observed actively washing and distributing superglacial drift. Assuming, as I think we must, that the englacial drift is crowded in the basal layers of the ice, enormous wastage of the ice must occur before it becomes superglacial; and the extreme brittleness and consequent fissuring of the ice protect it from the ravages of superglacial streams, until in the course of time it becomes forest-clad and assumes the character of an ancient soil.

It seems to me very probable, however, that when considerable sections or areas of the Pleistocene ice-sheet were so far wasted as to be absolutely stagnant, and when superglacial drift covered its surface and checked the melting of the ice, the still existing crevasses may have become choked with drift to such an extent as to keep the streams superglacial or in channels open to the sky, and thus to realize the essential conditions of the formation of modified drift from superglacial drift. Meanwhile, however, or before these conditions are realized, the water resulting from the melting of thousands of feet of ice has escaped from the ice-sheet through subglacial channels, and during its entire subglacial course the main body of the englacial drift has been within its reach and undergoing modification. This consideration and

the contemplation of the deposits being made at the present time by the Fountain stream, the Yahtse, and other rivers emerging from the base of the Malaspina glacier, not to multiply examples, satisfy me that not only is the modified drift, so far as it is being formed at the present time, the product chiefly of subglacial streams acting on englacial drift, but that it probably was so in Pleistocene times. When it is generally recognized that the modified drift requires not one but several theories, criteria will, doubtless, be established by which we may determine for any normal example whether it has been derived chiefly from subglacial, englacial, or superglacial drift.

The Transportation Argument.

Notwithstanding the abundant and indubitable evidence that a small part of the drift of the Pleistocene ice-sheet is far-traveled, it is generally conceded that the great bulk of the drift is of relatively local origin, and good authorities hold that this is substantially true for the modified drift as well as till. My own studies in the Boston Basin have satisfied me, however, that the modified drift and till of this region are somewhat contrasted in this respect, though perhaps not more than we should expect, considering that the modified drift was transported by water as well as by ice. For example, with the aid of several students in the Massachusetts Institute of Technology, I examined the composition of a prominent esker on the northwest shore of Weymouth. North of this point in the line of glacial movement are three broad belts of rocks: First, slates and conglomerates of the Boston Basin (Carboniferous), about thirteen miles; second, hornblendic granites, diorite and felsite, with some Cambrian slate and quartzite, eight to ten miles; third, mica schists, muscovite granites and gneiss, pegmatite, etc., extending into New Hampshire. We found, on looking over some tons of material, that of all which was coarse enough for easy identification about 50 per cent. is from the first belt, 40 per cent. from the second, and 10 per cent. from the third. Subsequently, at points only two to five miles from the northern edge of the Boston Basin, I found the proportion of material from the first belt in the modified drift very small, 10 per cent or less. Hence it is probably safe to assume that more than half of the coarser material of the modified drift of the Boston Basin is five to ten miles from its source and a good fraction as much as twenty miles.

But conceding that the readily identifiable constituents of the drift,

whether modified or unmodified, are chiefly of distinctly local origin, it may still be doubted whether much weight should be attached to this fact as an argument against the view that practically the entire volume of the drift was englacial in the earlier and maximum stages of the ice-sheet. For the purpose of this discussion the drift may be divided into three parts: First, the preglacial detritus, which must have been chiefly of a residuary and clayey character and highly oxidized (red and yellow), like the residuary soils of the South; second, the finer products of glacial erosion, rock flour, etc., formed chiefly on stoss slopes and for the most part unoxidized; third, the coarser part of the drift, the identifiable rock fragments, which must be almost wholly of glacial origin and derived chiefly from the lee slopes.

The preglacial residuary and sedentary soil was probably partly swept away by aqueous erosion during the elevation of the continent and before the formation of the ice-sheet. What was left of it probably became incorporated with the ice-sheet in its earliest stage; and we may well suppose that during the various vicissitudes of the ice-sheet, and through the coöperation or alternation of glacial, lacustrine, and fluvial transportation, it has been carried in large part beyond the limits of the glaciated area. Certainly there is little indication of its presence in the composition of the drift; and experiment shows that an admixture of a very small proportion of highly oxidized residuary clay, like that of the South, with a typical till is readily detected in the change of color. It is a natural suggestion, therefore, that the Lafayette and Columbian formations of the South have been derived, along their northern borders, in part from the preglacial residuary soils of the North. The finely comminuted and unoxidized glacial detritus constitutes now the basis or matrix of the till, and is very largely represented in the modified drift. But except to a very limited extent it is entirely unidentifiable as to its source and the distance of its transportation. The vast deposits of modified drift in Southeastern New England, and the great average thickness of till in Ohio and other interior States, not to mention distinctly morainal accumulations, indicate, however, when compared with the scanty deposits of drift over many northern areas in New England and Canada, that a large volume of the older, finer, and less readily identifiable part of the drift is relatively far-traveled. In its earliest stages the ice-sheet, we may reasonably suppose, wore away and absorbed a considerable thickness of rotten rock underlying the residuary soil; and during its max-

imum stage, as already noted, the hard rocks suffered glacial abrasion on the lee slopes as well as on the stoss slopes. The conditions must then have been very unfavorable to the rending of the ledges and the detachment of fragments and bowlders; but this came later with the decline of the ice-sheet, when the flowage pressure so far predominated over the vertical pressure that the ice pulled away from instead of following down the lee slopes.

Approaching the subject in this way, I can see no escape from the conclusion that the rock fragments and bowlders must date chiefly from the later stages of the ice-sheet. Hence they must have been, in general, the last material to be absorbed by the ice-sheet and the first to be deposited by basal melting. Under favorable conditions of flexing or shearing a small part of this material attained a high level in the ice and enjoyed a long glacial transport; but the fact that most of it is still near the parent ledges will, I judge, be found quite consistent with the englacial theory if due allowance be made for the relatively short time that it was inclosed in the ice and for its basal position and the low velocity of the basal layers of the ice. Although the total forward movement of the ice, as indicated by far-traveled erratics, appears to have been as much as five or six hundred miles, and even in some parts of the glaciated areas perhaps a thousand miles, a basal slipping of one twentieth of that distance or less would probably be regarded as sufficient to account for the erosion of the bed-rock surface and the normal distribution of the identifiable fragments. In this connection I venture to repeat the suggestion that possibly the total movement of the ice has been overestimated, the more distant erratics having been, perhaps, transported in part by water, and not wholly by the ice-sheet, each marked recession of the ice-sheet providing a series of glacial lakes and rivers along its margin.

Since writing out this paper I have realized more distinctly than before that the points relating to the entire volume of the drift having been englacial during the active erosion of the bed-rock, the efficient protection afforded glaciated surfaces by even a thin layer of till, and the consequent ruling out of drag as a mode of glacial transportation have been previously stated by Mr. Upham.[1] But since I have approached the subject in quite a different way, and there are still minor points of difference, this general acknowledgment is, perhaps, preferable to any attempt at quotation.

[1] Bull. Geol. Soc. Amer., 5, 71–86, etc.

SOME EXPERIMENTS ON THE GROWTH OF DIATOMS.

By GEORGE C. WHIPPLE, S.B.

Received April 14, 1896.

In a paper published in 1894 the writer suggested an explanation for the peculiar seasonal distribution of diatoms in lakes and ponds. It was shown that in deep ponds these minute plants are found abundantly during the spring and fall, but are almost entirely absent during the summer and winter; that these growths are closely connected with the phenomena of circulation and stagnation of the water, which phenomena are due to temperature changes; and that it is during the periods of the year when the water is in complete circulation throughout the vertical that the diatom growths occur. The explanation offered for these facts had reference chiefly to the food supply. It was stated that diatoms require a sufficient supply of nitrogen in the form of nitrates, and that they require a free circulation of air; and it was shown how during the "periods of circulation" in the spring and fall these conditions were fulfilled. In the light of more extended observations and experiments this food supply theory, taken alone, is seen to be inadequate, and while it is true that the question of food is one of fundamental importance, yet there are other factors which materially influence their growth. With a view to determining the nature and effect of some of these influences the writer has conducted during the past year several series of experiments, some of the results of which are here presented.

It is not an easy matter to cultivate diatoms successfully in the laboratory to obtain comparative results. They are organisms which have an extremely sensitive nature, and slight changes in their environment often make great differences in their growth. The temperature, the amount of light, the shape and size of the jar in which they are grown, the action of the glass upon the water, etc., are all disturbing elements affecting their growth. Take, for example, the shape of the jar. On one occasion three portions of a sample of

Cochituate water were placed in three jars of various shapes, each of which held 500 cc. In the first the water had a depth of 25 cm. and a surface area of 20 sq. cm.; in the second the depth was 7.1 cm. and the area 70 sq. cm.; in the third the depth was 2.7 cm. and the area 186 sq. cm. The three jars were placed side by side on the window sill so that they received practically the same amount of light, and the temperature was found by observation to be the same in each case. The water in each jar originally contained 226 diatoms per cc. After standing ten days the water in the first jar contained 685 per cc.; in the second jar, 1,537; and in the third jar, 7,585. Of the last 6,060 were Synedra, 1,080 Melosira, 235 Tabellaria, 200 Asterionella, 10 Stephanodiscus. The large number per cc. in the third jar was no doubt partly caused by greater evaporation from the large surface exposed and the consequent higher concentration of the organisms, but it was chiefly due to the greater opportunity for the absorption of air. In the deep jar the water could not take up the oxygen and carbonic acid from the air as fast as the diatoms used them up. Moreover the diatoms settled to the bottom of the jars, where they grew as a brown, velvety layer. The distance of these growths from the surface also affected their supply of air.

Another experiment made at the same time gave similar results. Into three cylinders, equal in diameter, were poured different quantities of the same sample of water. The first contained 100 cc., the second 200 cc., and the third 500 cc., the depths being, respectively, 1.4 cm., 2.9 cm., and 7.1 cm. The original water contained 226 diatoms per cc. After ten days the first jar contained 2,288, the second 1,733, and the third 1,537 per cc.

To more clearly illustrate the fact that diatoms do not grow without air two cultures of reservoir water were made in flasks, one being open to the air and the other covered with a thin layer of oil. The water originally contained 150 per cc. After twenty-five days the open flask contained 7,648 per cc., while the other contained but 192. An attempt to force a growth of diatoms in a flask by allowing air to continually bubble up through the water was a failure, the agitation produced being more than the delicate plants could stand.

It was also found in the laboratory experiments that the position of the jars in the window caused marked variations in the intensity of the growths. Those on the side of the window where the light was strongest gave the heaviest growths, except in one spot where

the sunlight fell; there the growth was small. These facts led to a more extensive investigation to determine the effect of light of varying intensities. It was known, of course, that, in common with all chlorophyllaceous plants, diatoms will not grow in the dark, and it was also known that exposure to bright sunlight will kill them, but between the bright sunlight and total darkness there was a wide field for experiment.

A variety of preliminary experiments was made to determine the best method of regulating the intensity of the light and of securing such conditions that the results would be fairly comparable. They all showed that in the laboratory it was next to impossible to secure the desired result. It was therefore decided to make the experiments in the ponds themselves, under conditions as nearly as possible like those found in nature.

The method employed was an extremely simple one. It consisted of suspending bottles filled with water from the same source at different depths in the pond, the bottles being tied to a rope which hung from an anchored buoy. After a certain time the bottles were drawn to the surface and the water examined, records being kept of the number of diatoms in each sample before and after exposure. The bottles varied in capacity from 150 to 1,000 cc. In the first five experiments they were tightly stoppered, but in the later ones silk bolting cloth was tied over the mouths of the bottles, and inverted glass tumblers were placed above. The latter arrangement gave much heavier growths on account of providing better opportunity for the circulation of air and for the renewal of food supply.

The results of the experiments are given in tabular form at the end of this paper. Before discussing them, however, it will be appropriate to consider the subject of the nature and intensity of the light at various depths in the water.

This subject has not been as thoroughly investigated as its importance appears to demand, and most of the investigations that have been made were made upon the clear water of the ocean or of large lakes. Perhaps the most complete study of the transparency of water was that made by Professor F. A. Forel upon the water of Lake Leman in Switzerland.

His experiments are fully described in the second volume of his recent monograph, entitled *Le Léman.*[1] Three methods of ex-

[1] Forel, F. A. Le Léman, monographie limnologique, Lausanne, 1895.

periment were employed. The first was that of the visibility of plates. This method, first used by Secchi in 1865 in determining the transparency of the water of the Mediterranean Sea, consisted of lowering a white disk (20 cm. in diameter) into the water and noting the depth at which it disappeared from view, and then raising it and noting the point at which it reappeared. The mean of these two depths was called the limit of visibility. The second method, known as that of the Genevan Commission, was similar to the first, but instead of a white disk an incandescent light was lowered into the water. This light when seen through the water from above presented an appearance similar to that of a street lamp in a fog, that is, there was a bright spot surrounded by a halo of diffused light. When the light was lowered into the water this bright spot first disappeared from view. The depth of this point was noted as the "limit of clear vision." Finally the diffused light disappeared, and the depth of this point was noted as the "limit of diffused light." Both the first and second methods were useful only in comparing the relative transparency of different waters or of the same water at different times. In order to get an idea of the intensity of light at different depths a photographic method was used. Sheets of sensitized albumen paper were prepared and mounted in a frame in such a way that half of the sheet was covered with a black screen, while the other half was exposed. A series of these papers was attached to a rope and lowered into the water; they were at equal distances apart, and so supported that they assumed a horizontal position in the water. They were placed in position during the night and allowed to remain twenty-four hours. On the next night they were drawn up and placed in a toning bath. A comparison of the prints made at different depths enabled the observer to determine the depth at which the light ceased to affect the plates and to obtain some idea of the relative intensity of the light at the different depths. To assist in this comparison an arbitrary scale was made by exposing sheets of the same paper to bright sunlight for different lengths of time.

The results of the experiments are given by Forel as follows:

In Lake Leman the limit of visibility of a white disk 20 cm. in diameter was 21 m. The limit of clear vision of a 7-candle-power incandescent lamp was 40 m.; the limit of diffused light was about 90 m. The depth at which the light ceased to have any effect on

the photographic paper was 100 m. when the paper was sensitized with chloride of silver, and about 200 when sensitized with iodobromide of silver. These depths were much less in summer than in winter on account of the increased turbidity of the water. The transparency of the water of other lakes, as shown by the limit of visibility of a white disk, is cited as follows: Lake Tahoe, 33 m.; La Mer des Antilles, 50 m.; Lac Lucal, 60 m.; Mediterranean Sea, 42.5 m.; Pacific Ocean, 59 m. It should be remembered that these are all comparatively light-colored waters, and that in them the light penetrates to far greater distances than in the brown-colored and more or less turbid water of many of our New England ponds. For example, in the Chestnut Hill Reservoir a plate lowered into the water at a time when the color was 0.92 disappeared from view at a depth of only 6 feet.[1]

The decrease in the intensity of light below the surface is due to two causes: First, the absorption of a certain portion of the light by the water; and second, the presence of fine particles in suspension, which act as a screen to shut out the light. The coefficient of absorption of light by water is practically unknown. It varies greatly, of course, with the quality of the water. Wild[2] gives the following figures for distilled water, and shows that the power of absorption increases with the temperature:

Temperature.	Intensity of light after passing through 1 dm. of distilled water.[3]
24.4° Cent.	0.9179
17.0° "	0.93968
6.2° "	0.94769

[1] Recent experiments by the writer have shown that the limit of visibility may be determined most accurately by using a disk about 8 inches in diameter, divided into quadrants painted alternately black and white, like the target of a level rod, and looking vertically down upon it through a water telescope provided with a suitable sun-shade. It has been found that the limit of visibility obtained in this manner bears a very close relation to the turbidity of the water, and it seems quite possible that this simple experiment may be of considerable value in determining the relative turbidities of different waters.

[2] Wild, H. "Ueber die Lichtabsorption der Luft," Poggendorfs Annalen, Anhang, cxxxiv, 582, Berlin, 1868.

[3] Forel considers these values too low, and with this the writer concurs.

The reduction of light in passing through water is supposed to follow the law that as the depth increases arithmetically the intensity of the light decreases geometrically. For example, if the intensity of

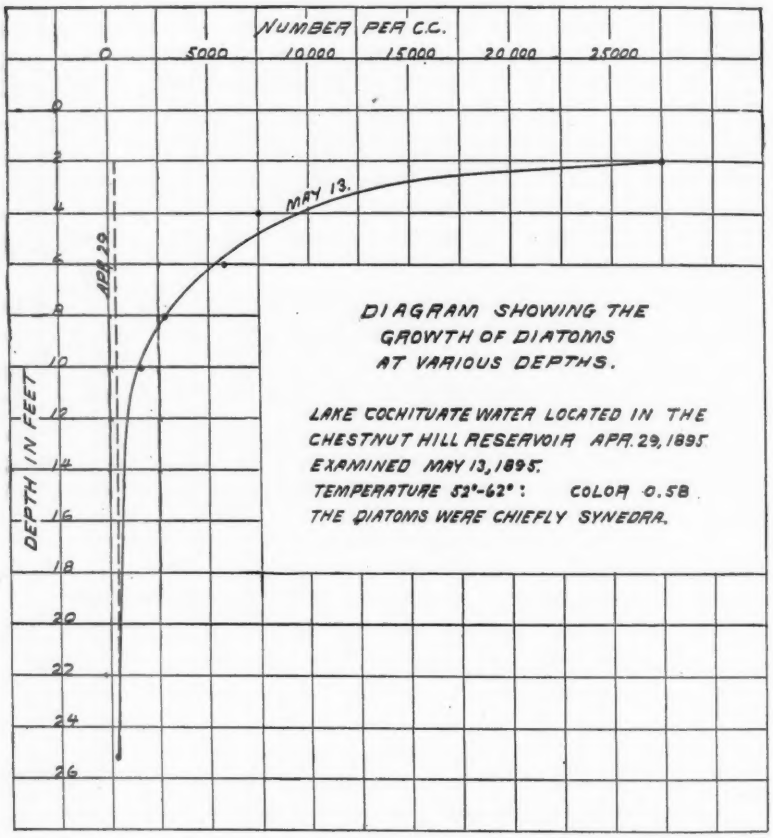


FIG. 1.

the light falling upon the surface of a pond is represented by 1, and if $\frac{1}{4}$ of the light is absorbed by the first foot of water, then the intensity of light at the depth of one foot will be $\frac{3}{4}$; the second foot of water will absorb $\frac{1}{4}$ of $\frac{3}{4}$, and the intensity at a depth of 2 feet

will therefore be $\frac{9}{16}$, and so on. At this rate of decrease the intensity of light at a depth of 10 feet will be only about 5 per cent. of that at the surface.

In regard to the quality of the light at different depths there is little accurate data to be obtained. In a general way, however, it may be said that the red and yellow rays are most readily transmitted.

The practical question to be decided by the experiments was not the exact amount of light necessary for the development of diatoms, but the depth below which they are unable to grow and the difference in the growths at various depths caused by variations in the intensity of the light. The observations here recorded are offered as a partial answer to these questions.

Fig. 1 shows the results of one series of observations. Bottles were filled with Cochituate water and located in Chestnut Hill Reservoir at depths of 2, 4, 6, 8, 10, and 25 feet, where they remained from April 29 to May 13, 1895. During this time the temperature varied from 53° to 62°, and the color of the water in which they were immersed was 0.58 (Platinum Standard). The relative growths at the different depths are shown by the curve, the number of diatoms in the original water being indicated by the broken line. Near the surface, it will be observed, there was a vigorous growth, there being more than 25,000 diatoms per cc. Most of these were Synedra. At greater depths the numbers were less, and at the bottom there were fewer than in the original sample. In Experiments Nos. 3 to 7 the "surface" samples were so placed that at times they were partially above the water, and therefore exposed to varying atmospheric temperatures and occasionally to direct sunlight. The effect was seen in diminished growth. In those series the maximum growth was found just below the surface. In the other experiments the "surface" samples were immersed about 6 inches. These always gave the maximum growths. In Experiment No. 8 there were two "surface" samples — one just above the surface and one immersed 6 inches. The latter gave the greater growth.

At what depth do the diatoms cease to develop, that is, at what depth is the intensity of the light so weak that it is incapable of furnishing the energy sufficient for their growth? The experiments show what we should naturally expect, that it depends upon the character of the water — its color, turbidity, etc. This is illustrated by

Fig. 2, which shows the results of two series of experiments upon water of the same kind located in Lake Cochituate and Chestnut Hill Reservoir. The former had a color of 0.33, while the color of the latter was 0.87. The difference between the two series is very striking. In the light-colored water the growths were heavier and extended to greater depths than in the darker water. Curve No. 1

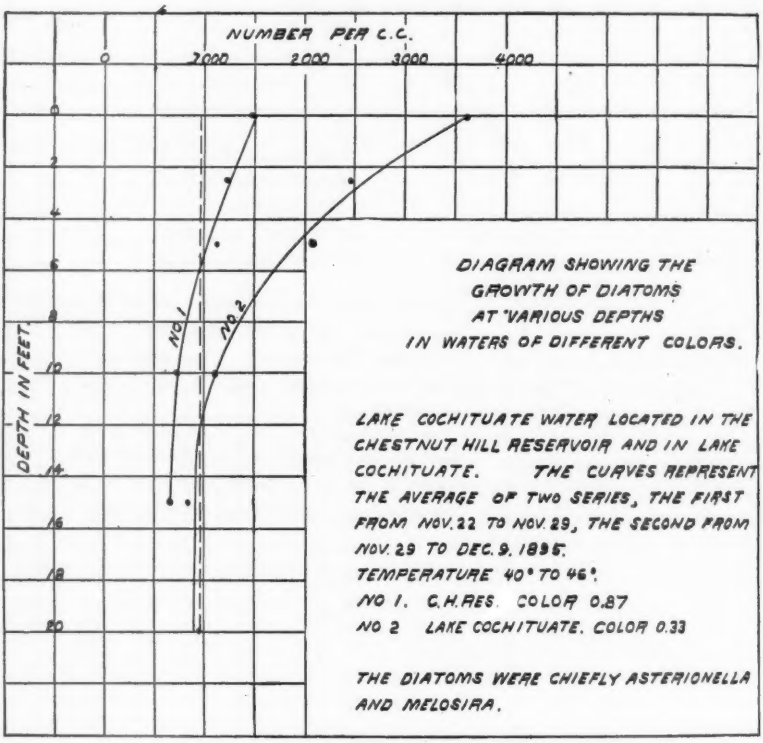


FIG. 2.

represents the growths in Chestnut Hill Reservoir, and Curve No. 2 those in Lake Cochituate. The number of diatoms in the original sample is shown by the broken line. The point at which this broken line cuts the curves may be called the limit of growth. In Lake Cochituate this point was at a depth of about 12 feet; in Chestnut Hill Reservoir, 6 feet.

This limit of growth has been determined for each series of experiments. It varies considerably, but may be shown to be dependent largely upon the color of the water. If, for example, we divide the

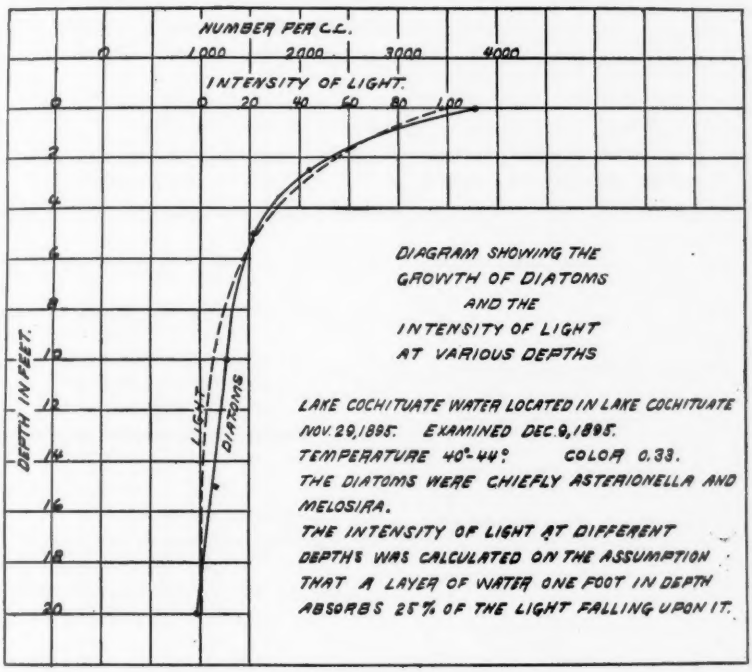


FIG. 3.

experiments into groups according to the color of the water, we obtain the following average values:

Number of Observations.	Average Color. (Platinum Standard.)	Average Limit of Growth in Feet.
5	0.29	15
5	0.60	12
2	0.86	8

Thus we see that in the dark waters the limit of growth is about 8 feet, while in the light waters it is about 15 feet. The limit of

growth in a perfectly clear, colorless water is unknown, but the experiments of Forel and others indicate that it might be found at a considerable depth.

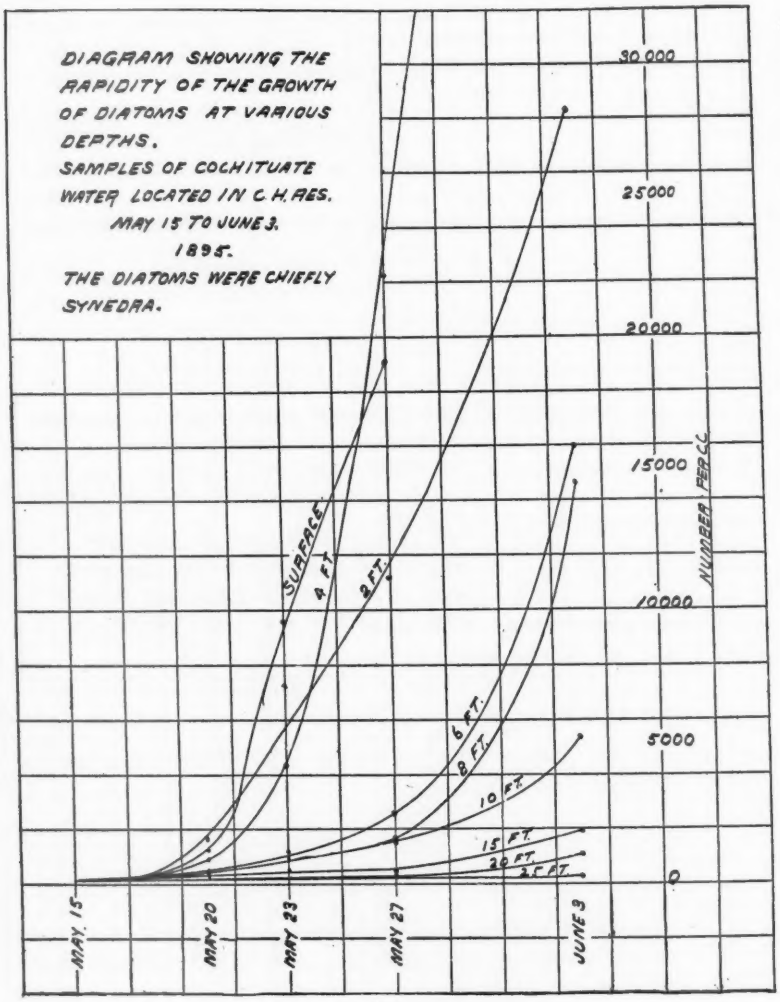


FIG. 4.

In order to appreciate better the fact that the extent of the growth of diatoms depends upon the intensity of the light, let us consider Experiments Nos. 9 and 10. These two series of experi-

ments were made at a time when the temperature of the water in the reservoir was almost exactly the same from the surface to the bottom. The average of the results of these two experiments is shown in Fig. 3. In connection with these experiments the coefficient of absorption of light by the water was approximately determined in the laboratory, and the intensity of light was calculated for the different depths. These values are shown by the broken line in Fig. 3. The parallelism of this line with that representing the growth of diatoms is very striking.

Fig. 4 shows the results of a series of experiments in which several examinations of each sample were made. These emphasize the fact that the rate of growth varies with the amount of light.

In Experiment No. 8 complete microscopical examinations were made. The diatoms, however, were the only organisms that developed extensively. Near the surface a few of the green algæ were seen during the first week or two. The Cyanophyceæ (chiefly a form of Anabæna) increased slightly at first and then began to disappear. Some of the infusoria developed to a slight extent near the surface. Whether this was on account of the difference in the amount of light or in the larger amount of food material near the surface is uncertain. It should be noticed that the amorphous matter increased from week to week, and that it was most abundant near the surface. As a supplement to this experiment, the bottle which had been suspended for three weeks at a depth of 20 feet was brought to the surface on November 30 and supported at a depth of 1 foot. On December 7 the diatoms, which at the bottom had decreased to 149 per cc., were 278 per cc. and in a healthy condition. They would doubtless have increased still more had not the experiment been accidentally terminated.

Diatoms are said to be positively heliotropic, that is, they tend to move towards the light. In some species this power is quite strong; in others it is less noticeable. For the purpose of determining the heliotropism of the diatoms commonly found in water supplies, samples of water rich in diatoms were placed in brass tubes 3 inches in diameter and 32 inches long, having glass ends. One end was covered with a black cap, and the other end exposed to the light. After varying lengths of exposure, portions of the water were drawn from each end of the tubes and examined microscopically. As an example of the results obtained the following may be quoted. Cochituate

water containing 992 diatoms per cc. was exposed in a tube for twelve hours. At the end of that time the water at the light end of the tube contained 1,438, and that at the dark end only 320. Some of the tubes were inclined, to see if the diatoms would move upwards towards the light; some of them were placed vertically; in others the diatoms were given time to settle before the exposure was made. The experiments showed that most of the common genera tended to move towards the light while settling, but that having once reached the bottom of the tube they remained where they fell. They apparently did not possess the power of moving upwards towards the light — certainly not through any great depth of water. But while they could not rise of their own accord, slight currents of convection caused by varying the temperature of the water sufficed to keep them near the surface.

The inability of certain diatoms to rise towards the light of their own accord was also shown by another experiment. Glass tubes $1\frac{1}{4}$ inches in diameter and 5 feet long, open at the lower end but closed at the top, were suspended in the reservoir at a time when Tabellaria and Stephanodiscus were numerous. The tops of the tubes were level with the surface of the water, and were so arranged that samples could be drawn from the closed ends. After these tubes were allowed to stand for a few hours it was almost invariably found that the diatoms had settled and that the water at the top of the tubes was practically free from them. Other experiments along this line are in progress, and it is hoped that some interesting results will be reached.

The bearing which these facts have upon the seasonal distribution of diatoms is obvious, and we are now better able to understand why it is that their growths occur during those seasons of the year when the water is in circulation throughout the vertical. During those periods not only is food more abundant, but the vertical currents keep the diatoms near the surface, where there is light enough to stimulate their growth, and where there is an abundance of air. If this theory be true, it must follow that the weather has a marked influence upon their growth. We should expect that the greatest growths would occur on warm, fair days, when there is just wind enough to keep the diatoms near the surface. On quiet days we should expect that they would sink in the water, perhaps below the limit of their growth. During a long period of quiet weather they might sink even to such a depth that they would not again be able to reach the surface.

This is just what took place in Lake Cochituate in the spring of 1895. In this lake there is almost invariably a heavy spring growth of diatoms, but in 1895 the growth was small. It began as usual,

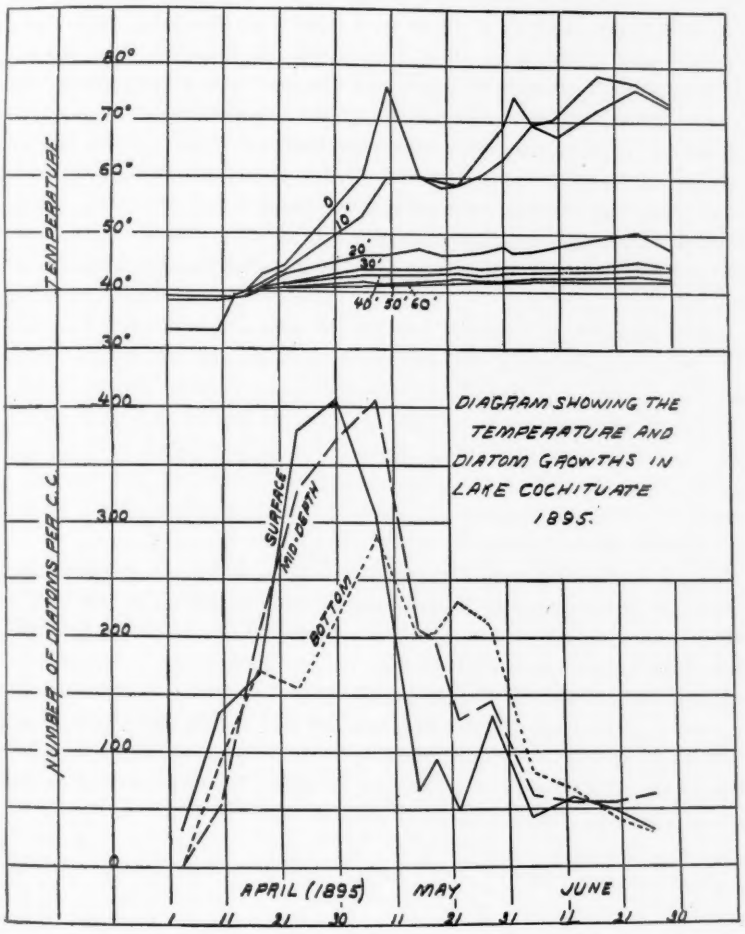


FIG. 5.

the diatoms being apparently in good condition. Early in May, however, there were a few days of uncommonly warm weather. The temperature of the air went above 90°, and the temperature of the

surface water on one day was 76°. For almost a week the water was very calm. During this calm weather the diatoms settled rapidly, disappearing almost entirely from the surface. In the meantime the water became stratified, on account of the high temperature of the surface layers, and when once more the wind began to blow its influence was felt only 10 or 15 feet below the surface. The diatoms, having settled below that depth, were unable to rise, and consequently their growth ceased. These facts are illustrated in Fig. 5. In Basin III, which is not nearly as deep as Lake Cochituate, the growth of diatoms was arrested during the same warm, quiet period, but inasmuch as circulation afterwards reached to the bottom the growth began again, and continued until the next warm, quiet period, which occurred in June, checked it. In this connection it will be recalled that when the ice forms over a pond the diatom growths usually cease (though several notable exceptions might be mentioned).

Since the growth of diatoms depends upon the intensity of light, and since this is greater in colorless than in dark-colored waters, we may naturally expect to find the most extensive growth in light-colored waters. While it is true that food supply is quite as important as light for the growth of these organisms, yet it is true that to a certain extent the light-colored waters do show the greatest tendency to develop diatom growths.

The writer has recently compared the diatom growths in fifty-seven ponds and reservoirs of Massachusetts, as given in the reports of the State Board of Health. The result of this comparison is shown in the following table. From this we see that most of the heaviest growths occur in the light-colored waters, while in the very dark waters there are few. The table also shows that high chlorine, high hardness, and high nitrogen are favorable to their growth. In other words, an abundant food supply and a light-colored water are among their favorable conditions.

Chemical Analysis. (Parts per 100,000.)		Number of Ponds and Reservoirs in which Diatoms are,—			
		Often above 1,000 per cc.	Occasionally above 1,000 per cc.	Usually between 100 and 500 per cc.	Always below 100 per cc.
Color (Nessler Scale.)	0 to 0.30	12	4	9	4
	0.30 to 0.60	6	2	4	0
	0.60 to 1.00	6	1	5	1
	1.00 to ——	0	1	1	1
Excess of Chlorine	0	4	2	1	2
	.01 to .03	8	1	8	2
	.04 to .25	8	3	10	2
	.25 to —	4	2	0	0
Hardness	0 to 0.5	2	1	3	3
	0.5 to 1.0	7	4	5	2
	1.0 to 2.0	8	0	10	1
	2.0 to —	7	3	1	0
Nitrogen as Albuminoid Ammonia, (In solution.)	0 to .0100	2	0	2	1
	.0100 to .0150	6	1	5	3
	.0150 to .0200	8	6	7	1
	.0200 to ——	8	1	5	1
Nitrogen as Free Ammonia	0 to .0010	3	2	5	3
	.0010 to .0030	6	1	10	2
	.0030 to .0100	8	5	4	1
	.0100 to ——	7	0	0	0
Nitrogen as Nitrates	0 to .0050	3	3	5	6
	.0050 to .0100	11	3	13	0
	.0100 to .0200	6	1	1	0
	.0200 to ——	4	1	0	0

The writer has avoided reference to particular genera, for the reason that the experiments were hardly extensive enough to draw any general conclusions. The fact was noticed, however, that different genèra require different amounts of light for their best growth. Melosira, for instance, do not require as much light as Synedra. In Experiment No. 2 Melosira were found growing at a depth of 10 feet. In this connection it is interesting to note that Melosira sink in the water more rapidly than many of the common diatoms. It is very seldom, even during a vigorous growth, that they are found more abundant at the surface than at greater depths. It may be that on account of their tendency to sink in the water they have gradually become adapted to their dark environment, and are able to get along with less light than other diatoms. Asterionella, on the other hand, is slow in settling. Even in quiet weather it is found most abundant at the surface. This genus is known to be slightly motile, and it may be that when supplied with a flood of light its power of heliotropism becomes sufficient to overcome the effect of gravity.

In most ponds where diatoms flourish different genera come and go in a most irregular manner; they develop one after another or they all grow at once; sometimes only one genus appears. As yet no theory has been advanced to account for their erratic succession. It is quite possible, however, that the cause may be found to be connected with their motility, their relative specific gravity, and their sensitiveness to light.

In conclusion the writer desires to express his obligations to Mr. W. F. Murphy and Mr. C. E. Livermore, who have kindly assisted him in the various experiments.

EXPERIMENT NO. 1.

Sudbury Water located in Chestnut Hill Reservoir. April 8–29, 1895.
Temperature, 39–53° F. Color, 0.56.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Navicula.	Total.
April 8	All depths.	8	0	1	1	8	0	18
April 29	1 ft.	110	0	4	1,896	16	0	2,026
April 29	5 ft.	162	0	2	54	132	2	352
April 29	10 ft.	0	0	0	3	0	0	3
April 29	15 ft.	0	0	0	2	0	0	2
April 29	20 ft.	0	0	0	8	0	0	8
April 29	25 ft.	0	12	0	6	0	0	18

EXPERIMENT NO. 2.

Cochituate Water located in the Chestnut Hill Reservoir. April 29 to May 13, 1895.
Temperature, 53°–62°. Color, 0.58.

Date.	Depth.	Number per cc.					
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Total.
April 29	All depths.	94	196	3	11	15	319
May 13	2 ft.	4,040	910	20	22,010	550	27,530
May 13	4 ft.	570	80	10	6,800	120	7,580
May 13	6 ft.	380	650	26	4,510	284	5,850
May 13	8 ft.	650	840	26	1,304	100	2,920
May 13	10 ft.	154	1,380	10	80	0	1,624
May 13	25 ft.	16	132	0	88	28	264

EXPERIMENT NO. 3.

Cochituate Water located in the Chestnut Hill Reservoir. May 15 to June 3, 1895. Temperature, 62°–68°. Color, 0.57.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Miscellaneous.	Total.
May 15	All depths.	61	29	12	17	10	0	129
May 20	Surface.	196	28	12	896	104	0	1,236
"	2 ft.	108	32	20	1,408	56	0	1,624
"	4 "	116	56	36	584	80	0	872
"	6 "	88	20	32	288	28	0	456
"	8 "	56	8	24	136	24	0	248
"	10 "	0	0	36	220	8	0	264
"	15 "	48	24	8	192	28	0	300
"	20 "	16	16	32	204	16	0	284
"	25 "	80	36	20	104	0	0	240
May 23	Surface.	140	0	40	9,340	80	0	9,600
"	2 ft.	80	0	80	6,870	0	220	7,250
"	4 "	572	76	48	3,464	204	0	4,364
"	6 "	176	36	60	1,020	104	0	1,396
"	8 "	256	76	48	500	68	0	948
"	10 "	56	56	16	904	24	0	1,056
"	15 "	60	16	20	376	56	0	528
"	20 "	20	0	0	400	0	0	420
"	25 "	12	20	24	152	8	0	216
May 27	Surface.	200	0	60	18,800	40	0	19,100
"	2 ft.	0	0	0	10,100	80	20	10,200
"	4 "	140	100	60	21,550	290	10	22,150
"	6 "	70	50	90	4,580	90	0	4,880
"	8 "	188	56	40	1,184	160	0	1,628
"	10 "	60	92	8	1,256	64	8	1,488
"	15 "	104	56	16	316	16	4	512
"	20 "	40	32	16	404	0	0	492
"	25 "	0	16	20	96	16	0	148
June 3	Surface.	...	...	..	.....	...	...	.....
"	2 ft.	170	0	0	28,050	40	0	28,260
"	4 "	0	0	0	88,600	40	0	88,640
"	6 "	0	0	20	15,850	110	0	15,980
"	8 "	160	0	30	14,250	170	0	14,630
"	10 "	80	120	50	5,140	0	0	5,390
"	15 "	80	20	10	1,830	0	0	1,940
"	20 "	60	80	20	950	10	0	1,120
"	25 "	50	20	20	70	70	0	230

EXPERIMENT NO. 4.

Cochituate Water (from depth of 30 ft.) located in Lake Cochituate. May 31 to June 7, 1895. Temperature, 64°–70°. Color, 0.29.

Date.	Depth.	Number per cc.					
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Total.
May 31	All depths.	31	62	2	2	7	104
June 7	Surface.	350	0	70	380	0	800
June 7	2½ ft.	120	40	80	11,100	50	11,390
June 7	5 ft.	310	0	40	2,030	160	2,540
June 7	10 ft.	32	0	8	44	28	112
June 7	15 ft.	20	0	8	24	8	60
June 7	20 ft.	48	12	8	12	4	84
June 7	25 ft.	24	0	8	32	12	76
June 7	30 ft.	24	48	8	4	16	100
June 7	40 ft.	56	16	28	4	40	144
June 7	50 ft.	40	48	12	20	28	148
June 7	60 ft.	12	56	12	44	40	164

EXPERIMENT NO. 5.

Sudbury Water located in the Chestnut Hill Reservoir. June 5 to June 19, 1895. Temperature, 67°–72°. Color, 0.57.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Miscellaneous.	Total.
June 5	All depths.	6	0	17	12	72	13	120
June 12	Surface.	120	0	0	520	690	0	1,330
June 12	5 ft.	0	0	0	9,500	100	0	9,600
June 12	10 ft.	32	0	20	980	140	0	1,172
June 12	15 ft.	16	0	8	776	72	0	872
June 12	20 ft.	16	0	16	112	64	0	208
June 12	25 ft.	0	0	20	68	192	0	280
June 19	Surface.	..	..	..	....	...	..	....
June 19	5 ft.	40	0	90	28,000	40	0	28,170
June 19	10 ft.	0	0	30	2,870	60	0	2,960
June 19	15 ft.	200	40	80	210	160	0	690
June 19	20 ft.	0	0	12	268	68	0	348
June 19	25 ft.	12	12	60	120	76	0	280

EXPERIMENT NO. 5A.

Cochituate Water located in the Chestnut Hill Reservoir. June 5 to June 19, 1895. Temperature, 67°–72°. Color, 0.57.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Miscellaneous.	Total.
June 5	All depths.	0	0	27	4	8	10	49
June 12	Surface.	110	0	0	300	760	0	1,170
June 12	5 ft.	0	0	10	1,840	80	0	1,930
June 12	10 ft.	16	0	4	888	28	0	936
June 12	15 ft.	0	0	40	72	0	0	112
June 12	20 ft.	24	0	20	182	24	0	252
June 12	25 ft.	0	0	36	16	4	0	56
June 19	Surface.	..	..	..	.....	..	..	.....
June 19	5 ft.	0	0	20	16,800	0	0	16,820
June 19	10 ft.	0	0	20	10,550	40	0	10,610
June 19	15 ft.	0	0	40	280	20	0	340
June 19	20 ft.	0	0	40	330	0	0	370
June 19	25 ft.	0	0	90	60	0	0	150

EXPERIMENT NO. 6.

Cochituate Water (from depth of 60 ft.) located in the Chestnut Hill Reservoir. July 11 to July 26, 1895. Temperature, 69°–77°. Color, 0.58.

Date.	Depth.	Number per cc.					
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Total.
July 11	All depths.	2	30	8	4	0	44
July 26	Surface.	0	0	0	328	0	328
July 26	2½ ft.	0	32	0	8	0	40
July 26	5 ft.	0	0	0	4,400	0	4,400
July 26	7½ ft.	0	0	0	1,472	0	1,472
July 26	10 ft.	0	0	0	140	56	196
July 26	12½ ft.	0	72	0	32	12	116
July 26	15 ft.	0	60	0	48	68	176
July 26	17½ ft.	0	0	0	32	24	56
July 26	20 ft.	0	24	0	8	0	32
July 26	25 ft.	0	0	0	12	4	16

EXPERIMENT NO. 7.

Reservoir Water located in Lake Cochituate and Basin 3. August 7 to August 17, 1895. Temperature, 70°–78°. Color: Lake Cochituate, 0.28; Basin 3, 0.68.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Cyclotella.	Total.
August 7	All depths.	0	0·	25	0	84	3	112
		Lake Cochituate.						
August 17	Surface.	6	0	0	78	102	0	186
August 17	2½ ft.	0	0	0	72	432	20	524
August 17	5 ft.	0	0	0	82	212	12	306
August 17	7½ ft.	..	..	..	..	...	..	...
August 17	10 ft.	0	0	0	20	184	30	234
August 17	15 ft.	0	0	0	2	50	12	64
August 17	20 ft.	0	0	4	8	56	24	92
August 17	30 ft.	0	0	0	6	46	2	54
		Basin 3.						
August 17	2½ ft.	0	0	18	28	340	26	412
August 17	5 ft.	0	0	0	52	158	46	256
August 17	7½ ft.	0	0	0	12	140	2	154
August 17	10 ft.	0	0	0	8	38	0	46

EXPERIMENT NO. 8.

Cochituate Water located in the Chestnut Hill Reservoir. November 8 to November 30, 1895. Temperature, 40°–45°. Color, 0.83.

Date.	Depth.	Number of Standard Units per cc.						
		Diatomaceæ.	Chlorophyceæ.	Cyanophyceæ.	Fungi.	Infusoria.	Total organisms.	Amorphous.
November 8	All depths.	463	4	487	1	36	991	280
November 12	Above surface.	1,278	30	580	4	27	1,919	376
" "	Surface.	1,564	0	632	16	136	2,348	440
" "	2½ ft.	664	5	532	0	95	1,296	308
" "	5 "	676	17	488	8	20	1,209	344
" "	7½ "	520	0	564	12	8	1,104	324
" "	10 "	475	0	476	0	11	962	448
" "	15 "	527	3	384	0	16	930	284
" "	20 "	437	0	456	0	34	927	240
November 16	Above surface.	1,381	0	355	0	20	1,756	555
" "	Surface.	3,075	0	680	0	117	3,872	685
" "	2½ ft.	1,055	13	265	0	83	1,416	375
" "	5 "	665	13	600	15	14	1,307	295
" "	7½ "	440	20	460	0	7	927	310
" "	10 "	543	15	515	0	67	1,140	375
" "	15 "	375	9	465	0	0	849	270
" "	20 "	514	0	375	10	0	899	280
November 23	Above surface.[1]	1,051	0	0	0	4	1,055	850
" "	Surface.	3,464	0	460	0	0	3,924	860
" "	2½ ft.	859	0	470	0	7	1,336	680
" "	5 "	261	0	240	0	15	516	345
" "	7½ "	103	0	215	0	4	322	310
" "	10 "	65	0	155	0	0	220	190
" "	15 "	....	..	...	..	...	....	...
" "	20 "	130	0	40	0	4	174	255
November 30	Above surface.	....	..	...	..	...	....	...
" "	Surface.	3,681	0	50	0	25	3,756	1,115
" "	2½ ft.	1,043	18	220	0	5	1,286	965
" "	5 "	248	0	110	0	4	362	700
" "	7½ "	259	0	95	0	4	358	710
" "	10 "	168	0	25	0	0	193	600
" "	15 "	....	..	...	..	...	....	....
" "	20 "	149	0	10	0	20	179	460

[1] Sample frozen.

EXPERIMENT NO. 9.

Cochituate Water located in Lake Cochituate and the Chestnut Hill Reservoir.
November 22 to 29, 1895. Temperature, 42°–46°.
Color: Lake Cochituate, .33; Chestnut Hill Reservoir, .90.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Miscellaneous.	Total.
November 22	All depths.	824	244	8	24	8	8	1,116
Lake Cochituate.								
November 29	Surface.	2,820	675	20	0	0	20	3,535
November 29	2½ ft.	2,540	285	10	0	10	0	2,845
November 29	5 ft.	2,180	290	10	0	50	0	2,530
November 29	7½ ft.	1,485	495	5	50	5	0	2,040
November 29	10 ft.	840	110	0	0	0	5	955
November 29	15 ft.	290	205	15	0	0	10	520
November 29	30 ft.	520	360	10	40	20	0	950
November 29	50 ft.	285	520	10	0	15	5	835
Chestnut Hill Reservoir.								
November 29	2½ ft.	1,070	125	10	0	10	0	1,215
November 29	5 ft.	770	230	5	0	20	0	1,025
November 29	7½ ft.	840	310	5	0	0	0	1,155
November 29	10 ft.	485	140	10	0	0	0	635
November 29	15 ft.	470	145	25	0	0	0	640

EXPERIMENT NO. 10.

Lake Cochituate Water located in Lake Cochituate and the Chestnut Hill Reservoir.
November 29 to December 9, 1895.
Temperature, 40°–44°. Color: Lake Cochituate, .33; Chestnut Hill Reservoir, .84.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Miscellaneous.	Total.
November 29	All depths.	625	150	13	17	0	5	810
Lake Cochituate.								
December 9	Surface.	3,010	685	35	60	0	0	3,790
December 9	2½ ft.	1,570	505	25	0	0	0	2,100
December 9	5 ft.	1,240	240	40	20	0	0	1,540
December 9	10 ft.	990	270	0	0	0	0	1,260
December 9	15 ft.	865	260	15	0	20	0	1,160
December 9	20 ft.	680	230	15	0	30	0	955
Chestnut Hill Reservoir.								
December 9	Surface.	895	435	40	60	50	0	1,480
December 9	2½ ft.	1,125	265	20	0	10	0	1,420
December 9	5 ft.	965	260	30	0	0	0	1,255
December 9	10 ft.	510	170	55	10	0	0	745
December 9	15 ft.	110	430	20	60	55	0	675

NOTES ON THE BEST FORM OF CROSS SECTION FOR THE COILS OF A GALVANOMETER.

I. When the Needle Is Indefinitely Short.[1]

By FRANK A. LAWS, S.B.

Received May 11, 1896.

The deduction of the equation of the curve bounding the best form of cross section of the coil of a galvanometer is usually made subject to conditions, which may be stated as follows:

A given length of wire is to be wound into a coil, and the cross section of the coil must be such that with a given *P. D.* between its terminals the axial component of magnetic force at the center is a maximum.

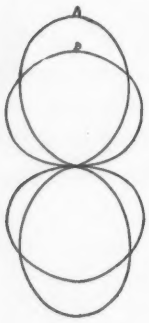
Consider a unit length of wire bent into a circular arc, and let its trace on a plane containing the axis of the coil be defined by the coördinates r and θ, let E be the axial component at center of coil due to the unit length of wire when carrying a unit current, then the equation $r^2 = \frac{I}{E_v} \sin \theta$ gives the locus along which each centimeter of wire will have the same efficacy. This equation is that of the boundary of the best form of cross section, for any transfer of a given length of wire outwards moves it into a position of less efficacy. This is one solution of the general problem; that it is not the only one will appear if the conditions are examined. The solution given is for the case where the resistance of the galvanometer has a determining influence on the current flowing through it. It would, for instance, apply when the instrument is to be used as a current galvanometer under conditions such that the solution for the best galvanometer resistance is applicable, or when the instrument is to be used as a potential galvanometer, for, in order that this instrument may be applicable to any particular piece of work, it must have a resistance above a certain limit, which is fixed by the work in hand. In both cases mentioned, immediately the size of wire is given the problem reduces to the best disposition of a given volume of wire.

[1] The experimental determination of the curves bounding the best form of cross section for the two cases given above, but when the needle is of finite dimensions, is in progress.

A solution corresponding to different conditions may be derived. The problem may be stated thus: Determine the best form of cross section of the coils of a galvanometer when the current through the instrument is independent of its resistance, or, in other words, is controlled by conditions external to the instrument. In order to give definiteness to the problem the area of cross section must be given.

The field at the center of the coil due to one turn, the coördinates of its trace being r, θ is $F = 2\pi c \frac{\sin^2 \theta}{r}$, the measure of the efficacy of a turn is $2\pi \frac{\sin^2 \theta}{r}$; denote this by E_c, then $r = \frac{2\pi}{E_c} \sin^2 \theta$.

Consider that the space within the curve $r = \frac{2\pi}{E_c} \sin^2 \theta$ is entirely filled with wire. Any replacement of one of the turns by another outside this area decreases the efficacy of the coil as a whole. That the length of wire may be altered is immaterial, for by the conditions of the problem the current is independent of the resistance of the instrument.



As any replacement of turns by others in space not occupied by the coil diminishes the field at the center of the coil, the form of cross section outlined by the equation $r = \frac{2\pi}{E_c} \sin^2 \theta$ is the best under the conditions imposed. This second solution — that for a given cross section — corresponds to the case of the ammeter, for the fundamental principle of ammeter design is that the introduction of the instrument into the circuit shall not alter the current which it is desired to measure.

Above are given the outlines of the cross sections corresponding to both solutions, the areas inclosed by the curves being equal.

The curve A shows the solution when the condition is that of a given cross sectional area, and curve B the solution when the condition is that of a given volume of coil.

Rogers Laboratory of Physics,
Massachusetts Institute of Technology,
Boston, March, 1896.

RESULTS OF TESTS MADE IN THE ENGINEERING LABORATORIES.

V.

Received June 12, 1896.

Applied Mechanics.

Tests on Bolted Joints.

The following eight tests form a part of a series not yet finished. This series was planned so as to get an increasing compression per square inch in front of the rivets; the object being to find the effect of this increasing compression on the efficiency of the joint and on the tensile strength of the net section of plate.

All specimens were made from the same sheet of boiler plate, the tensile strength of which was taken from the average of three tests as 68,000 pounds per square inch. The bolts were of machine steel nicely turned. The tensile strength of the bolt steel was 96,300 pounds per square inch, this being the average of three tests. The holes in the plate were drilled and rimmed, and the bolts were fitted so as to be an easy driving fit with a machinist's hammer. The force with which the bolts were set up is noted on some of the tests. Micrometer readings of the stretch of the joints were taken from both the top and the bottom sides, there being two sets of measuring points on each side. The dimensions of the joints are shown in the table following. The accompanying cuts show the joints after fracture.

SUMMARY OF TESTS ON BOLTED JOINTS.

Number of joint.	Size of bolts.	Pitch.	Thickness of plate.	Width of joint.	Area of net section.	Maximum load.	Maximum tension per sq. in. net section.	Maximum shear per sq. in. on bolts.	Maximum compression per sq. in.	Average thickness in front of bolts at fracture.	Reduction of area. (Net section.)	Efficiency.
1	[illegible]"	2"	.43"	6.01"	1.62	102,000	63,100	38,500	105,400	.49"	31%	58%
2	[illegible]"	2"	.43"	6.00"	1.61	101,100	62,600	38,100	104,500	.49"	15%	57%
3	[illegible]"	2 1/16"	.43"	7.69"	2.18	137,000	62,900	38,000	121,000	.51"	28%	61%
4	[illegible]"	2 1/16"	.43"	7.70"	2.18	136,000	62,300	37,700	120,500	.52"	30%	60%
5	1"	3 1/16"	.44"	9.76"	2.97	179,500	60,400	38,100	136,000	.57"	28%	62%
6	1"	3 1/16"	.44"	9.76"	2.97	180,700	60,800	38,300	136,900	.58"	23%	62%
7	1 1/4"	4"	.45"	12.00"	3.88	238,500	61,500	39,900	158,600	.59"	25%	65%
8	1 1/4"	4"	.45"	12.00"	3.88	225,500	58,100	37,600	148,600	.56"	26%	62%

Joint No. 2 broke by shearing.

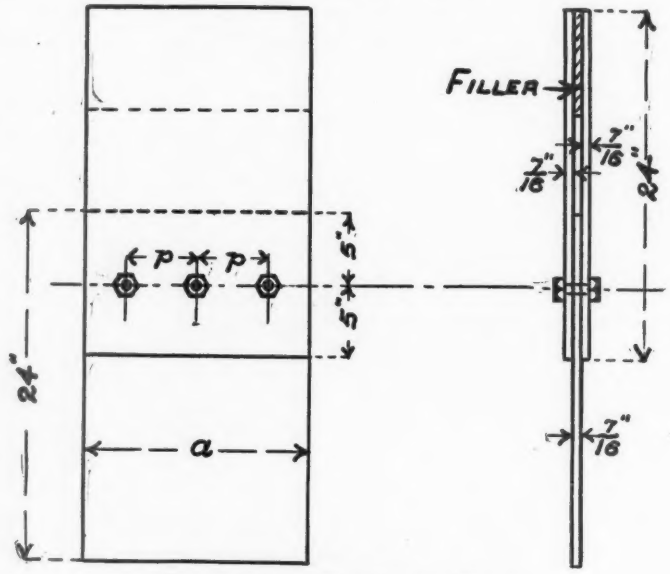


FIG. 1. GENERAL DIMENSIONS OF JOINTS.

Distance between measuring clamps = 12".

No.	*d*	*p*	*a*
1- 2	7/8"	2"	6"
3- 4	7/8"	2 1/16"	7 11/16"
5- 6	1"	3 1/16"	9 3/16"
7- 8	1 1/4"	4"	12"
9-10	1 1/4"	4 7/16"	14 1/16"
11-12	1 1/4"	5 1/16"	17 1/16"

d = diameter of bolts. *p* = pitch. *a* = width of plate.

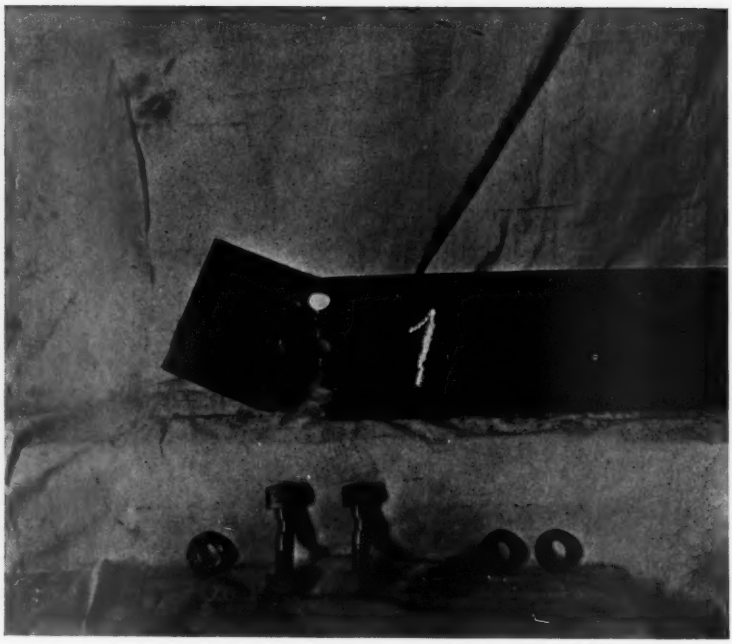


FIG. 2. BOLTED JOINT, NO. 1.

TEST ON BOLTED JOINT. No. 1. (FIG. 2.)

Date, November 5, 1895.

Loads.	North Side.				South Side.				North Side.		South Side.		Average difference.	Total difference.
	Top.	Top.	Bottom.	Bottom.	Top.	Top.	Bottom.	Bottom.	Mean.	Difference.	Mean.	Difference.		
1,500	.0678	.0675	.0923	.0923	.4723	.4726	5125	.5123	.0500	....	.4924	....	....	....
3,500	.0070	.0672	.0928	.0930	.4720	.4725	.5150	.5152	.0500	.0000	.4937	.0013	.0007	....
5,500	.0080	.0682	.0933	.0931	.4730	.4732	.5155	.5156	.0507	.0007	.4943	.0006	.0007	.0014
6,500	.0083	.0679	.0938	.0936	.4736	.4740	.5163	.5166	.0509	.0002	.4951	.0008	.0005	.0019
	Load dropped off for 21 hours; plate strained to 13,500, and load dropped again for 21 hours.													
6,500	.0746	.0748	.1072	.1073	.4863	.4862	.5378	.5378	.0910	....	.5120	....	....	....
9,500	.0759	.0757	.1078	.1076	.4867	.4867	.5383	.5382	.0918	.0008	.5125	.0005	.0007	.0026
12,500	.0762	.0763	.1088	.1088	.4871	.4869	.5383	.5382	.0925	.0009	.5126	.0001	.0005	.0031
18,500	.0768	.0770	.1085	.1083	.4900	.4901	.5395	.5394	.0927	.0002	.5150	.0024	.0013	.0044
24,500	.0755	.0753	.1074	.1073	.4950	.4948	.5445	.5443	.0914	—.0013	.5197	.0047	.0017	.0061
27,500	.0772	.0772	.1089	.1090	.4950	.4948	.5444	.5446	.0931	.0017	.5198	.0001	.0009	.0070
30,500	.0786	.0785	.1097	.1098	.4954	.4953	.5450	.5452	.0942	.0011	.5202	.0004	.0008	.0078
33,500	.0790	.0788	.1099	.1111	.4954	.4954	.5461	.5463	.0950	.0008	.5208	.0006	.0007	.0085
	Load dropped off for 21 hours.													
33,500	.0800	.0801	.1112	.1113	.4980	.4978	.5483	.5484	.0957	....	.5231	....	....	....
36,500	.0813	.0813	.1120	.1120	.4988	.4990	.5492	.5493	.0967	.0010	.5240	.0009	.0010	.0095
39,500	.0864	.0862	.1168	.1170	.4973	.4973	.5485	.5485	.1016	.0049	.5229	—.0011	.0019	.0114
42,500	.0886	.0884	.1200	.1201	.4976	.4975	.5498	.5500	.1043	.0027	.5237	.0003	.0018	.0132
48,500	.0917	.0917	.1252	.1253	.5015	.5016	.5538	.5540	.1085	.0042	.5277	.0040	.0041	.0173
51,500	.0972	.0973	315	.1313	.5027	.5025	.5573	.5574	.1143	.0058	.5300	.0023	.0041	.0214
54,500	.1080	.1082	.1438	.1440	.5065	.5063	.5625	.5627	.1260	.0117	.5345	.0045	.0081	.0295
	Load dropped off for 69 hours.													
54,500	.1058	.1059	.1406	.1408	.5127	.5127	.5653	.5653	.1232	....	.5390	....	....	....
60,500	.1324	.1322	.1683	.1683	.5178	.5179	.5717	.5716	.1503	.0271	.5448	.0058	.0165	.0460
66,500	.1684	.1682	.2048	.2048	.5200	.5200	.5717	.5719	.1866	.0363	.5459	.0011	.0187	.0647
72,500	.2331	.2329	.2690	.2692	.5168	.5168	.5707	.5705	.2511	.0645	.5437	—.0022	.0312	.0959
102,000	Maximum load. (Plate broke by tearing at one side and then shearing bolt on opposite side.)													

Size of bolts	$\frac{3}{4}$"	Maximum tension per sq. in. on net section of plate	63,100 lbs.
Pitch of bolts	2"	Maximum shear per sq. in. on bolt	38,500 lbs.
Thickness of plate	.43"	Maximum compression per sq. in. on plate,	105,400 lbs.
Width of plate	6.01"	Av. thickness of plate in front of bolts at fracture	.49 in.
Area net section of plate	1.62 sq. in.	Reduction of area of net section of plate	31%
		Efficiency of joint	58%

Bolts were set up with 60 lbs. pull on 10-in. wrench.

TEST ON BOLTED JOINT. No. 2. (Fig. 3.)

Date, November 12, 1895.

Loads.	North Side.				South Side.				North Side.		South Side.		Average difference.	Total difference.
	Top.	Top.	Bottom.	Bottom.	Top.	Top.	Bottom.	Bottom.	Mean.	Difference.	Mean.	Difference.		
500	.0375	.0375	.1231	.1229	.5729	.5728	.6657	.6658	.0803	....	.6193	....	....	....
5,500	.0352	.0352	.1213	.1211	.5767	.5765	.6700	.6702	.0782	—.0021	.6234	.0041	.0010	.0010
10,500	.0323	.0321	.1195	.1196	.5807	.5805	.6753	.6753	.0759	—.0023	.6280	.0046	.00115	.0022
15,500	.0290	.0290	.1176	.1176	.5852	.5853	.6806	.6806	.0733	—.0026	.6329	.0049	.00115	.0033
20,500	.0269	.0267	.1156	.1156	.5899	.5897	.6855	.6856	.0712	—.0021	.6377	.0048	.00135	.0047
	Load dropped off for 21 hours.													
20,500	.0274	.0272	.1151	.1152	.5917	.5917	.6877	.6876	.0712	....	.6397	....	....	....
25,500	.0240	.0241	.1115	.1113	.5979	.5979	.6939	.6940	.0677	— .0035	.6459	.0062	.0014	.0061
30,500	.0224	.0223	.1108	.1106	.6018	.6019	.6997	.6997	.0665	— .0012	.6508	.0049	.0019	.0080
35,500	.0173	.0173	.1062	.1064	.6117	.6116	.7091	.7092	.0618	— .0047	.6604	.0096	.0025	.0105
40,500	.0065	.0064	.0954	.0953	.6321	.6319	.7298	.7300	.0509	— .0109	.6810	.0206	.0049	.0154
45,500	—.0067	—.0067	.0820	.0818	.6572	.6573	.7546	.7546	.0376	— .0133	.7059	.0250	.0059	.0213
50,500	—.0114	—.0113	.0782	.0782	.6701	.6703	.7689	.7690	.0334	— .0042	.7196	.0137	.0048	.0261
55,500	—.0254	—.0252	.0650	.0652	.7026	.7028	.8030	.8028	.0249	— .0085	.7528	.0332	.0124	.0385
60,500	—.0347	—.0347	.0566	.0566	.7317	.7319	.8322	.8324	.0110	— .0140	.7821	.0293	.0077	.0462
65,500	—.0440	—.0440	.0489	.0489	.7806	.7808	.8820	.8822	.0025	—.00850	.8314	.0494	.0205	.0667
70,500	—.0385	—.0387	.0555	.0554	.8086	.8100	.9109	.9109	.0085	.0050	.8601	.0287	.0169	.0836
101,100	Maximum load. (Bolts sheared in succession, beginning on most strained side.)													

Size of bolts	¾″
Pitch of bolts	2″
Thickness of plate	.43″
Width of plate	6.00″
Area net section of plate	1.61 sq. in.

Bolts were set up with 60 lbs. pull on 10-in. wrench.

Maximum tension per sq. in. on net section of plate	62,600 lbs.
Maximum shear per sq. in. on bolts	38,100 lbs.
Maximum compression per sq. in. on plate,	104,500 lbs.
Av. thickness of plate in front of bolts at fracture	.49 in.
Reduction of area of net section of plate	15%
Efficiency of joint	57%

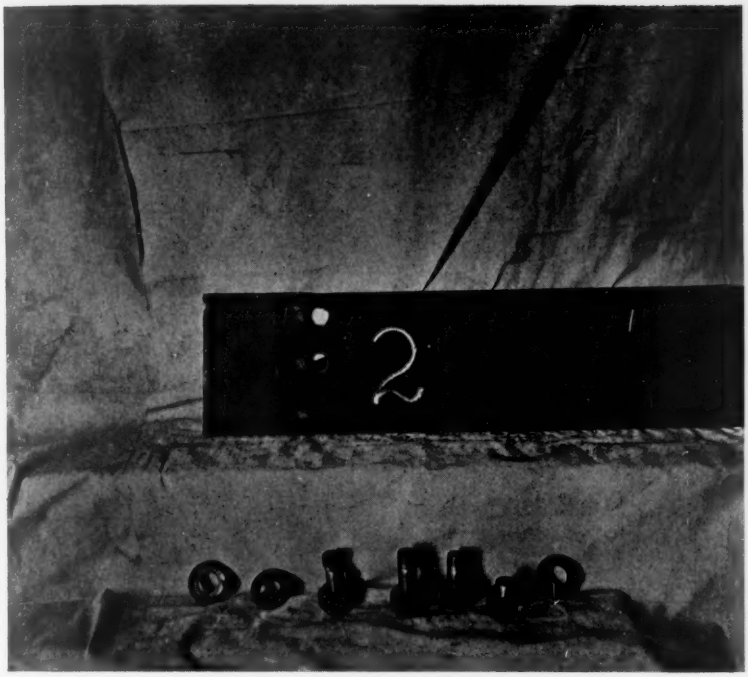


FIG. 3. BOLTED JOINT, NO. 2.

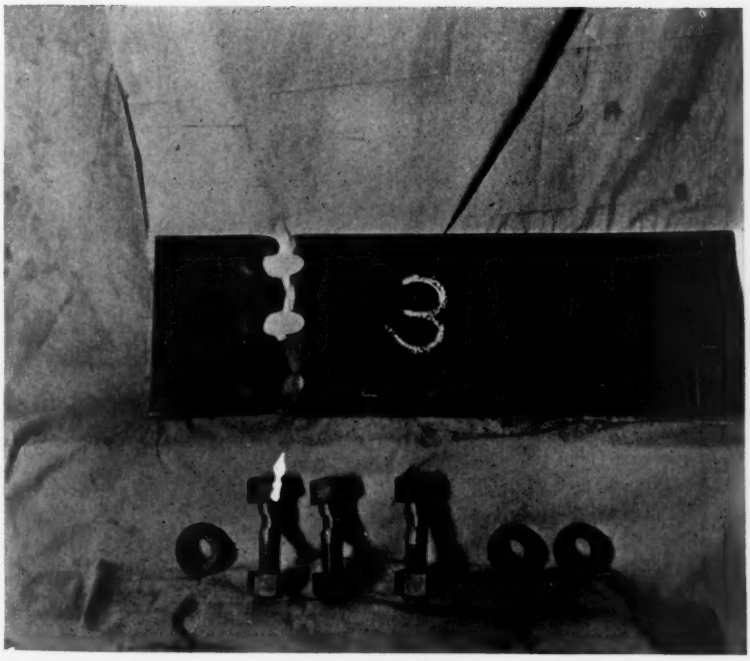


FIG. 4. BOLTED JOINT, NO. 3.

TEST ON BOLTED JOINT. No. 3. (FIG. 4.)

Date, November 14, 1895.

Loads.	North Side.				South Side.				North Side.		South Side.		Average difference.	Total difference.
	Top.	Top.	Bottom.	Bottom.	Top.	Top.	Bottom.	Bottom.	Mean.	Difference.	Mean.	Difference.		
500	.5157	.5158	.6168	.6168	.0332	.0333	.1534	.1532	.5663	....	.0933	....	....	....
5,500	.5191	.5193	.6176	.6175	.0335	.0335	.1491	.1490	.5684	.0021	.0913	—.0020	.0001	.0001
10,500	.5193	.5194	.6157	.6157	.0365	.0363	.1503	.1503	.5675	—.0008	.0934	.0021	.0007	.0008
15,500	.5174	.5173	.6140	.6138	.0408	.0408	.1539	.1537	.5657	—.0019	.0973	.0039	.0010	.0018
20,500	.5139	.5138	.6091	.6092	.0460	.0459	.1582	.1580	.5615	—.0042	.1020	.0047	.0003	.0021
25,500	.5134	.5134	.6069	.6069	.0500	.0500	.1615	.1613	.5602	—.0013	.1057	.0037	.0012	.0033
30,500	.5118	.5120	.6061	.6062	.0524	.0522	.1641	.1640	.5591	—.0011	.1082	.0025	.0007	.0040
	Load dropped off for 21 hours.													
30,500	.5120	.5122	.6104	.6104	.0541	.0542	.1654	.1654	.5613	....	.1098	....	....	....
35,500	.5110	.5112	.6079	.6079	.0578	.0579	.1693	.1693	.5595	.0018	.1136	.0038	.0010	.0050
40,500	.5068	.5067	.6030	.6030	.0670	.0678	.1783	.1782	.5549	.0046	.1226	.0090	.0022	.0072
45,500	.4859	.4859	.5820	.5818	.1128	.1128	.2225	.2227	.5339	.0110	.1677	.0451	.0171	.0243
50,500	.4833	.4834	.5784	.5785	.1193	.1192	.2289	.2289	.5309	.0030	.1748	.0071	.0021	.0264
55,500	.4821	.4823	.5780	.5781	.1237	.1238	.2328	.2328	.5301	.0008	.1783	.0035	.0014	.0278
60,500	.4794	.4794	.5741	.5742	.1339	.1332	.2421	.2422	.5268	.0033	.1877	.0094	.0031	.0309
65,500	.4534	.4534	.5474	.5474	.1959	.1958	.3037	.3037	.5004	.0470	.2497	.0620	.0075	.0384
70,500	.4504	.4504	.5447	.5449	.2060	.2058	.3139	.3137	.4975	.0029	.2599	.0102	.0037	.0421
75,500	.4413	.4414	.5360	.5360	.2306	.2305	.3381	.3380	.4887	.0088	.2803	.0294	.0103	.0524
80,500	.4325	.4324	.5261	.5260	.2573	.2575	.3651	.3649	.4798	.0089	.3112	.0219	.0065	.0589
85,500	.4203	.4205	.5140	.5139	.2970	.2972	.4041	.4043	.4672	.0126	.3507	.0395	.0135	.0724
90,500	.4060	.4062	.4992	.4994	.3441	.3442	.4507	.4507	.4527	.0145	.3974	.0467	.0161	.0885
137,000	Maximum load. (Joint gave way by plate tearing.)													

Size of bolts	$\frac{7}{8}''$	Maximum tension per sq. in. on net section of plate	62,900 lbs.
Pitch of bolts	$2\frac{9}{16}''$	Maximum shear per sq. in. on bolts	38,000 lbs.
Thickness of plate	.43″	Maximum compression per sq. in. on plate,	121,000 lbs.
Width of plate	7.69″	Av. thickness of plate in front of bolts at fracture	.51″
Area net section of plate	2.18 sq. in.	Reduction of area of net section of plate	28%
Bolts were set up with 60 lbs. pull on 11-in. wrench.		Efficiency of joint	61%

TEST ON BOLTED JOINT. No. 4. (FIG. 5.)

Date, November 18, 1895.

Load.	North Side.				South Side.				North Side.		South Side.		Average difference.	Total difference.
	Top.	Top.	Bottom.	Bottom.	Top.	Top.	Bottom.	Bottom.	Mean.	Difference.	Mean.	Difference.		
500	.2378	.2380	.2867	.2867	.4240	.4239	.4872	.4870	.2623	....	.4555	....	....	....
5,500	.2405	.2403	.2877	.2878	.4240	.4239	.4857	.4858	.2641	.0018	.4548	.0007	.0006	....
10,500	.2426	.2428	.2898	.2897	.4232	.4233	.4834	.4835	.2662	.0021	.4533	.0015	.0003	.0009
15,500	.2413	.2414	.2945	.2943	.4207	.4208	.4844	.4844	.2679	.0017	.4525	.0008	.0013	.0022
20,500	.2423	.2421	.2938	.2939	.4252	.4250	.4880	.4880	.2680	.0001	.4565	.0040	.0022	.0044
25,500	.2425	.2423	.2932	.2931	.4264	.4266	.4894	.4893	.2678	—.0002	.4579	.0014	.0006	.0050
30,500	.2382	.2380	.2930	.2932	.4298	.4297	.4920	.4920	.2656	—.0012	.4609	.0031	.0010	.0060
35,500	.2400	.2401	.2929	.2928	.4328	.4326	.4936	.4934	.2664	.0008	.4631	.0022	.0015	.0075
	Load dropped off for 21 hours.													
35,500	.2392	.2391	.2922	.2922	.4366	.4364	.4936	.4936	.2657	....	.4351	....	....	....
40,500	.2395	.2395	.2928	.2929	.4368	.4366	.4935	.4937	.2662	+.0005	.4652	.0001	.0003	.0078
45,500	.2389	.2391	.2924	.2925	.4391	.4393	.4968	.4968	.2657	—.0005	.4680	.0028	.0012	.0090
50,500	.2398	.2398	.2934	.2932	.4419	.4420	.4990	.4990	.2665	.0008	.4705	.0025	.0017	.0107
55,500	.2393	.2392	.2935	.2936	.4465	.4465	.5053	.5052	.2664	—.0001	.4759	.0054	.0027	.0134
60,500	.2378	.2378	.2922	.2922	.4549	.4548	.5127	.5128	.2650	+.0014	.4838	.0079	.0047	.0181
65,500	.2384	.2384	.2926	.2927	.4607	.4605	.5184	.5185	.2655	.0005	.4895	.0257	.0031	.0212
70,500	.2315	.2316	.2859	.2858	.4944	.4946	.5425	.5425	.2587	—.0068	.5185	.0290	.0111	.0323
75,500	.2307	.2307	.2861	.2861	.5023	.5023	.5802	.5802	.2574	—.0013	.5413	.0228	.0108	.0431
80,500	.2265	.2267	.2816	.2818	.5407	.5409	.6000	.6002	.2541	—.0033	.5705	.0292	.0130	.0561
85,500	.2353	.2353	.2901	.2901	.5641	.5642	.6222	.6223	.2627	.0086	.5933	.0228	.0157	.0718
90,500	.2460	.2461	.3015	.3015	.5930	.5932	.6521	.6519	.2738	.0111	.6226	.0293	.0202	.0920
95,500	.2689	.2689	.3249	.3249	.6148	.6148	.6737	.6736	.2969	.0231	.6442	.0216	.0224	.1144
100,500	.3004	.3005	.3322	.3322	.6392	.6392	.6994	.6994	.3103	.0134	.6693	.0251	.0193	.1337
105,500	.3472	.3472	.4503	.4504	.6653	.6658	.7268	.7271	.3988	.0885	.6963	.0270	.0578	.1915
136,000	Maximum load. (Joint gave way by plate tearing.)													

Size of bolts	$\frac{7}{8}$″	Maximum tension per sq. in. on net section of plate	62,300 lbs.
Pitch of bolts	$2\frac{3}{8}$″	Maximum shear per sq. in. on bolts	37,700 lbs.
Thickness of plate	.43″	Maximum compression per sq. in. on plates,	120,500 lbs.
Width of plate	7.70″	Av. thickness of plate in front of bolts at fracture	.52″
Area net section of plate	2.18 sq. in.	Reduction of area of net section of plate	30%
Bolts were set up with 60 lbs. pull on 11-in. wrench.		Efficiency of joint	60%

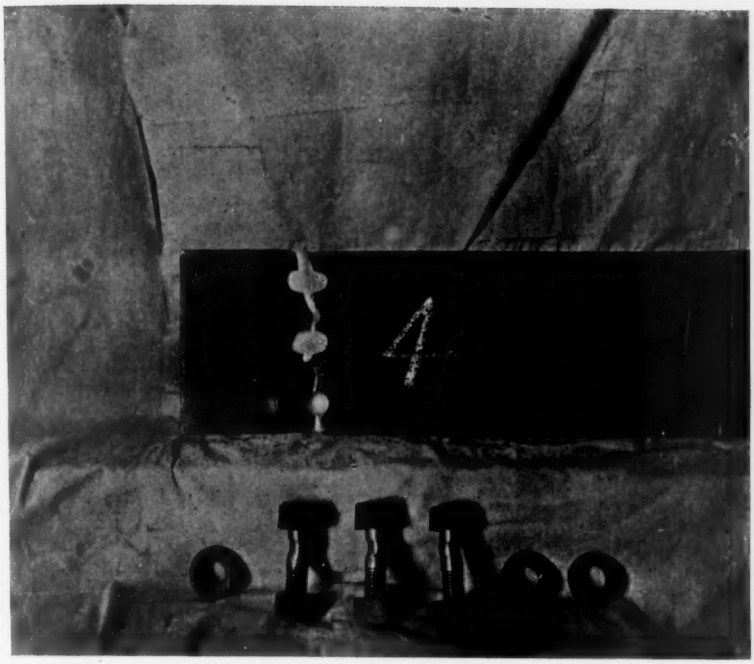


FIG. 5. BOLTED JOINT, NO. 4.

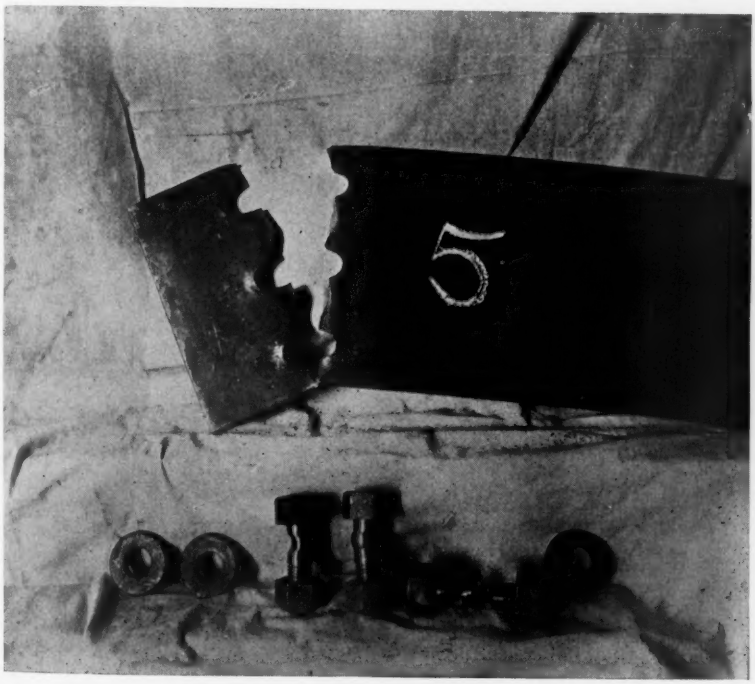


FIG. 6. BOLTED JOINT, NO. 5.

TEST ON BOLTED JOINT. No. 5. (FIG. 6.)

Date, November 22, 1895.

Loads.	North Side.				South Side.				North Side.		South Side.		Average difference.	Total difference.
	Top.	Top.	Bottom.	Bottom.	Top.	Top.	Bottom.	Bottom.	Mean.	Difference.	Mean.	Difference.		
500	.0316	.0314	.1576	.1576	.5521	.5520	.6770	.6768	.0945	....	.61447	....	....	....
5,500	.0311	.0311	.1576	.1575	.5541	.5540	.6798	.6799	.0943	—.0002	.61695	.0025	.0012	.0012
10,500	.0319	.0319	.1568	.1569	.5569	.5569	.6811	.6811	.0944	.0001	.61900	.0021	.0011	.0023
15,500	.0321	.0321	.1591	.1590	.5566	.5564	.6839	.6838	.0956	.0012	.62018	.0012	.0012	.0035
20,500	.0330	.0331	.1598	.1599	.5585	.5587	.6852	.6852	.0964	.0008	.62190	.0017	.0013	.0048
25,500	.0394	.0394	.1667	.1669	.5545	.5545	.6811	.6810	.1031	.0067	.61778	—.0041	.0013	.0061
Load dropped off for 69 hours.														
25,500	.0392	.0393	.1665	.1665	.5546	.5545	.6808	.6808	.1028	....	.6177	....	....	....
30,500	.0413	.0412	.1691	.1692	.5537	.5537	.6808	.6808	.1052	.0024	.6172	—.0005	.0010	.0071
35,500	.0423	.0422	.1709	.1709	.5541	.5542	.6812	.6812	.1066	.0014	.6177	—.0005	.0010	.0081
40,500	.0500	.0499	.1798	.1799	.5508	.5510	.6792	.6791	.1149	.0083	.6150	—.0027	.0028	.0109
45,500	.0526	.0527	.1828	.1828	.5504	.5505	.6789	.6789	.1177	.0028	.6147	—.0003	.0013	.0122
50,500	.0553	.0553	.1857	.1857	.5498	.5498	.6788	.6788	.1205	.0028	.6143	—.0004	.0012	.0134
55,500	.0727	.0729	.2062	.2062	.5409	.5409	.6717	.6719	.1395	.0190	.6064	—.0079	.0056	.0190
60,500	.0809	.0811	.2131	.2131	.5390	.5390	.6703	.6703	.1470	.0075	.6047	—.0017	.0029	.0219
65,500	.0849	.0851	.2188	.2190	.5378	.5378	.6689	.6689	.1519	.0049	.6034	—.0013	.0018	.0237
70,500	.1388	.1387	.2740	.2739	.5157	.5158	.6482	.6482	.2063	.0544	.5820	—.0014	.0165	.0402
75,500	.1568	.1566	.2932	.2933	.5068	.5068	.6403	.6404	.2250	.0187	.5736	—.0084	.0052	.0454
Load dropped off for 18 hours.														
75,500	.1573	.1572	.2944	.2942	.5058	.5059	.6393	.6394	.2258	....	.5726	....	....	....
80,500	.1598	.1599	.2968	.2968	.5060	.5059	.6396	.6398	.2283	.0025	.5728	.0002	.0013	.0467
85,500	.1992	.1994	.3364	.3366	.4958	.4957	.6298	.6297	.2679	.0396	.5627	—.0101	.0147	.0614
90,500	.2831	.2832	.4222	.4224	.4972	.4972	.6330	.6332	.3527	.0848	.5652	.0025	.0436	.1050
95,500	.2949	.2948	.4343	.4343	.5043	.5042	.6398	.6397	.3646	.0119	.5720	.0068	.0098	.1148
100,500	.2998	.2997	.4392	.4393	.5131	.5131	.6487	.6488	.3695	.0049	.5809	.0089	.0069	.1217
105,500	.3002	.3001	.4399	.4401	.5141	.5140	.6500	.6499	.3701	.0006	.5820	.0011	.0008	.1225
110,500	.3034	.3033	.4426	.4428	.5171	.5172	.6528	.6529	.3730	.0029	.5850	.0030	.0029	.1254
115,500	.3065	.3066	.4664	.4466	.5208	.5207	.6786	.6787	.3765	.0035	.5997	.0147	.0091	.1345
Load dropped off for 1 hour.														
115,500	.3342	.3340	.4785	.4787	.5468	.5470	.6831	.6832	.4064	....	.6150	....	....	....
120,500	.3359	.3361	.4809	.4809	.5518	.5516	.6891	.6889	.4085	.0021	.6204	.0054	.0038	.1383
125,500	.3604	.3602	.5052	.5050	.5752	.5752	.7116	.7118	.4327	.0242	.6435	.0231	.0237	.1620
130,500	.4064	.4063	.5473	.5472	.6097	.6095	.7462	.7463	.4768	.0441	.6779	.0344	.0785	.2405
179,500	Maximum load.													

Size of bolts	1″
Pitch of bolts	3¼″
Thickness of plate	.44″
Width of plate	9.76″
Area net section of plate	2.97 sq. in.

Bolts were set up with 60 lbs. pull on 12-in. wrench.

Maximum tension per sq. in. on net section of plate	60,400 lbs.
Maximum shear per sq. in. on bolts	38,100 lbs.
Maximum compression per sq. in. on plate,	136,000 lbs.
Av. thickness of plate in front of bolts at fracture	.57″
Reduction of area of net section of plate	28%
Efficiency of joint	62%

TEST ON BOLTED JOINT. No. 6. (FIG. 7.)

Date, December 3, 1895.

Loads.	North Side.				South Side.				North Side.		South Side.		Average difference.	Total difference.
	Top.	Top.	Bottom.	Bottom.	Top.	Top.	Bottom.	Bottom.	Mean.	Difference.	Mean.	Difference.		
500	.5631	.5632	.6570	.6568	.0683	.0683	.1732	.1733	.6100	....	.1208	....	....	....
5,500	.5593	.5594	.6607	.6605	.0698	.0698	.1787	.1786	.6100	.0000	.1242	.0034	.0017	.0017
10,500	.5594	.5594	.6570	.6570	.0738	.0736	.1802	.1800	.6082	—.0018	.1269	.0027	.0005	.0022
15,500	.5592	.5593	.6567	.6567	.0761	.0761	.1832	.1834	.6080	—.0002	.1297	.0028	.0013	.0035
20,500	.5592	.5592	.6581	.6582	.0770	.0772	.1850	.1852	.6087	.0007	.1311	.0014	.0011	.0046
25,500	.5607	.5605	.6580	.6582	.0787	.0785	.1860	.1862	.6094	.0007	.1324	.0013	.0010	.0056
30,500	.5617	.5618	.6593	.6594	.0804	.0802	.1878	.1877	.6105	.0011	.1340	.0016	.0014	.0070
35,500	.5612	.5614	.6594	.6592	.0824	.0823	.1898	.1896	.6103	—.0002	.1360	.0020	.0009	.0079
40,500	.5620	.5620	.6590	.6590	.0853	.0851	.1922	.1923	.6105	.0002	.1387	.0027	.0015	.0094
45,500	.5619	.5619	.6598	.6598	.0870	.0869	.1938	.1938	.6109	.0004	.1408	.0021	.0013	.0117
	Load dropped off for 2 hours.													
45,500	.5561	.5562	.6585	.6583	.0901	.0901	.1964	.1965	.6073	....	.1433	....	....	....
50,500	.5549	.5550	.6578	.6578	.0941	.0940	.1992	.1998	.6064	—.0009	.1469	+.0036	.0014	.0131
55,500	.5532	.5532	.6545	.6544	.1029	.1028	.2087	.2085	.6038	—.0026	.1557	.0088	.0031	.0162
60,500	.5514	.5512	.6543	.6545	.1084	.1084	.2147	.2148	.6028	—.0010	.1616	.0059	.0015	.0177
65,500	.5471	.5473	.6514	.6513	.1211	.1211	.2268	.2268	.5993	—.0035	.1739	.0123	.0044	.0221
70,500	.5445	.5447	.6457	.6458	.1337	.1338	.2383	.2384	.5952	—.0041	.1860	.0121	.0040	.0261
75,500	.5411	.5412	.6429	.6431	.1468	.1467	.2512	.2512	.5921	—.0031	.1990	.0130	.0049	.0310
80,500	.5213	.5211	.6222	.6222	.2183	.2181	.3218	.3217	.5717	—.0104	.2700	.0710	.0303	.0613
85,500	.5218	.5220	.6234	.6232	.2205	.2204	.3238	.3239	.5726	.0009	.2722	.0022	.0016	.0629
90,500	.5190	.5188	.6197	.6195	.2406	.2405	.3438	.3438	.5693	—.0043	.2922	.0200	.0078	.0707
95,500	.5178	.5178	.6198	.6198	.2593	.2595	.3630	.3630	.5688	—.0005	.3112	.0190	.0093	.0800
100,500	.5307	.5308	.6340	.6338	.2987	.2986	.4034	.4033	.5823	.0135	.3510	.0398	.0267	.1067
105,500	.5388	.5386	.6402	.6400	.3150	.3148	.4194	.4195	.5894	.0071	.3672	.0162	.0117	.1184
110,500	.5496	.5494	.6518	.6516	.3329	.3331	.4376	.4375	.6006	.0112	.3853	.0181	.0147	.1331
115,500	.5697	.5698	.6717	.6717	.3533	.3531	.4580	.4580	.6207	.0201	.4056	.0203	.0202	.1533
120,500	.5977	.5975	.6988	.6986	.3588	.3589	.4637	.4636	.6481	.0274	.4113	.0057	.0166	.1699
125,500	.6271	.6270	.7308	.7309	.3800	.3807	.4863	.4868	.6790	.0309	.4335	.0222	.0265	.1964
130,500	.6998	.6996	.8052	.8050	.4174	.4178	.5239	.5239	.7524	.0734	.4708	.0373	.0553	.2517
180,700	Maximum load.													

Size of bolts	1″	Maximum tension per sq. in. on net section of plate	60,800 lbs.
Pitch of bolts	3¼″	Maximum shear per sq. in. on bolts	38,300 lbs.
Thickness of plate	.44″	Maximum compression per sq. in. on plate,	136,900 lbs.
Width of plate	9.76″	Av. thickness of plate in front of bolts at fracture	.58″
Area net section of plate	2.97 sq. in.	Reduction of area of net section of plate	23%
Bolts were set up with 60 lbs. pull on 12-in. wrench.		Efficiency of joint	62%

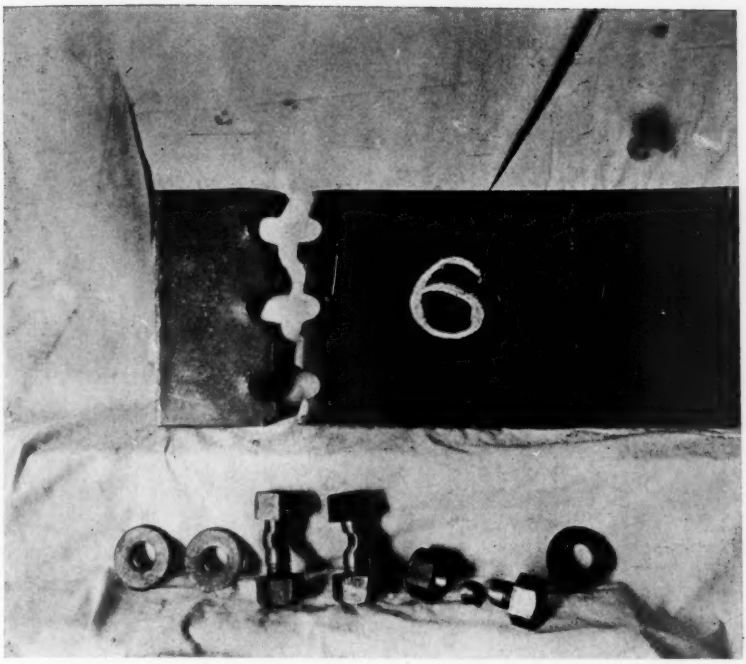


FIG. 7. BOLTED JOINT, NO. 6.

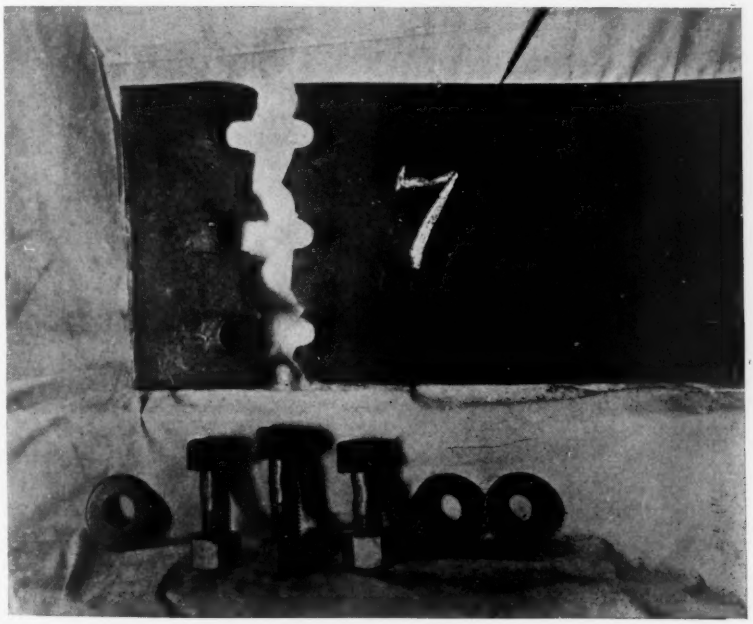


FIG. 8. BOLTED JOINT, NO. 7.

TEST ON BOLTED JOINT. No. 7. (FIG. 8.)

Date, December 5, 1895.

Loads.	North Side.				South Side.				North Side.		South Side.		Average difference.	Total difference.
	Top.	Top.	Bottom.	Bottom.	Top.	Top.	Bottom.	Bottom.	Mean.	Difference.	Mean.	Difference.		
500	.7285	.7286	.8469	.8471	.2549	.2549	.4038	.4036	.7878	....	.3293	....	....	....
5,500	.7325	.7323	.8442	.8441	.2577	.2579	.4022	.4023	.7883	.0005	.3300	.0007	.0006	.0006
10,500	.7345	.7344	.8444	.8444	.2587	.2585	.4014	.4013	.7894	.0011	.3300	—.0000	.0006	.0012
15,500	.7364	.7363	.8452	.8450	.2591	.2593	.4002	.4001	.7907	.0013	.3297	—.0003	.0005	.0017
	Load dropped off 2 hours.													
15,500	.7363	.7363	.8442	.8444	.2593	.2592	.4021	.4023	.7903	....	.3307	....	....	....
20,500	.7374	.7373	.8457	.8455	.2633	.2633	.4032	.4030	.7915	.0012	.3332	.0025	.0019	.0036
25,500	.7387	.7386	.8463	.8463	.2639	.2640	.4030	.4031	.7925	.0010	.3335	.0003	.0007	.0043
30,500	.7390	.7389	.8459	.8458	.2657	.2658	.4043	.4044	.7924	—.0001	.3351	.0016	.0008	.0051
35,500	.7393	.7393	.8462	.8460	.2669	.2671	.4058	.4058	.7927	.0003	.3364	.0013	.0008	.0059
40,500	.7387	.7388	.8453	.8453	.2700	.2700	.4077	.4079	.7920	—.0007	.3389	.0025	.0009	.0068
45,500	.7395	.7394	.8461	.8461	.2702	.2703	.4087	.4085	.7928	.0008	.3394	.0005	.0007	.0075
50,500	.7370	.7370	.8439	.8438	.2767	.2766	.4149	.4148	.7904	—.0024	.3458	.0064	.0021	.0095
55,500	.7364	.7364	.8431	.8432	.2797	.2797	.4177	.4178	.7898	—.0006	.3487	.0029	.0012	.0107
	Load dropped off 21 hours.													
55,500	.7252	.7253	.8430	.8430	.2794	.2794	.4173	.4172	.7841	....	.3483	....	....	....
60,500	.7300	.7300	.8422	.8422	.2830	.2830	.4209	.4210	.7861	.0020	.3520	.0037	.0028	.0135
65,500	.7273	.7271	.8391	.8393	.2942	.2941	.4324	.4323	.7832	—.0029	.3632	.0112	.0042	.0177
70,500	.7274	.7276	.8396	.8398	.2962	.2960	.4338	.4340	.7836	.0004	.3650	.0018	.0011	.0188
75,500	.7274	.7276	.8395	.8396	.2984	.2983	.4364	.4363	.7835	—.0001	.3673	.0023	.0011	.0199
80,500	.7265	.7265	.8387	.8387	.3039	.3040	.4424	.4422	.7826	—.0009	.3731	.0058	.0025	.0224
85,500	.7242	.7242	.8368	.8366	.3137	.3137	.4512	.4510	.7804	—.0022	.3824	.0093	.0035	.0259
90,500	.7224	.7222	.8347	.8348	.3237	.3235	.4621	.4621	.7785	—.0019	.3928	.0104	.0042	.0301
95,500	.7178	.7176	.8296	.8297	.3459	.3460	.4850	.4848	.7737	—.0048	.4154	.0226	.0089	.0390
100,500	.7176	.7174	.8300	.8302	.3516	.3517	.4904	.4906	.7738	.0001	.4211	.0057	.0029	.0419
105,500	.7180	.7180	.8307	.8309	.3610	.3611	.4996	.4998	.7744	.0006	.4304	.0093	.0049	.0468
110,500	.7224	.7222	.8346	.8348	.3683	.3685	.5077	.5078	.7785	.0041	.4381	.0077	.0059	.0527
115,500	.7284	.7283	.8418	.8419	.3795	.3793	.5193	.5192	.7851	.0066	.4493	.0112	.0089	.0636
120,500	.7261	.7260	.8400	.8400	.4007	.4007	.5418	.5417	.7830	—.0021	.4712	.0219	.0099	.0735
125,500	.7308	.7309	.8451	.8453	.4221	.4221	.5634	.5632	.7880	.0050	.4927	.0215	.0132	.0867
130,500	.7356	.7356	.8522	.8521	.4383	.4385	.5829	.5828	.7939	.0059	.5106	.0179	.0119	.0986
135,500	.7468	.7470	.8627	.8627	.4636	.4638	.6062	.6063	.8048	.0109	.5350	.0244	.0176	.1162
140,500	.7612	.7612	.8789	.8789	.4698	.4698	.6125	.6123	.8200	.0052	.5411	.0061	.0056	.1218
145,500	.7773	.7774	.8958	.8958	.4905	.4905	.6372	.6370	.8366	.0166	.5638	.0227	.0196	.1414
150,500	.7999	.7997	.9167	.9169	.5106	.5104	.6532	.6534	.8583	.0217	.5819	.0181	.0199	.1613
155,500	.8258	.8260	.9474	.9474	.5266	.5266	.6792	.6792	.8866	.0283	.6029	.0210	.0246	.1859
160,500	.8511	.8513	.9744	.9746	.5528	.5527	.7012	.7014	.9128	.0262	.6270	.0241	.0251	.2110
165,500	.8920	.8922	1.0162	1.0164	.5796	.5796	.7355	.7355	.9542	.0414	.6575	.0305	.0359	.2469
170,500	.9336	.9340	1.0584	1.0589	.6070	.6070	.7630	.7632	.9962	.0420	.6850	.0275	.0347	.2816
238,500	Maximum load. (Joint gave way by plate tearing.)													

Size of bolts	1⅛″	Maximum tension per sq. in. on net section of plate	61,500 lbs.
Pitch of bolts	4″	Maximum shear per sq. in on bolts	39,900 lbs.
Thickness of plate	.45″	Maximum compression per sq. in. on plate,	158,600 lbs.
Width of plate	12.00″	Av. thickness of plate in front of bolts at fracture	.59″
Area net section of plate	3.88 sq. in.	Reduction of area of net section of plate	25%
Bolts were set up with 60 lbs pull on 13-in wrench		Efficiency of joint	65%

TEST ON BOLTED JOINT. No. 8. (Fig. 9.)

Date, December 9, 1895.

Loads.	North Side.				South Side.				North Side.		South Side.		Average difference.	Total difference.
	Top.	Top.	Bottom.	Bottom.	Top.	Top.	Bottom.	Bottom.	Mean.	Difference.	Mean.	Difference.		
500	.6567	.6566	.6599	.6599	.1192	.1194	.1474	.1474	.6583	....	.1334	....	....	....
5,500	.6596	.6596	.6590	.6590	.1223	.1225	.1464	.1464	.6593	.0010	.1344	.0010	.0010	.0010
10,500	.6605	.6606	.6559	.6558	.1276	.1278	.1466	.1466	.6582	—.0009	.1372	.0028	.0009	.0019
15,500	.6605	.6605	.6548	.6549	.1294	.1294	.1473	.1475	.6577	—.0005	.1384	.0012	.0004	.0023
20,500	.6603	.6604	.6539	.6540	.1320	.1322	.1487	.1489	.6577	.0000	.1405	.0021	.0010	.0033
25,500	.6605	.6604	.6536	.6534	.1334	.1334	.1512	.1512	.6570	—.0007	.1423	.0018	.0006	.0039
30,500	.6605	.6603	.6528	.6530	.1353	.1355	.1512	.1512	.6567	—.0003	.1433	.0010	.0003	.0042
35,500	.6575	.6574	.6507	.6507	.1398	.1397	.1563	.1564	.6541	—.0026	.1481	.0048	.0011	.0053
	Load dropped off 70 hours.													
35,500	.6606	.6606	.6538	.6538	.1390	.1391	.1558	.1556	.6572	....	.1474	.0007	....	....
40,500	.6605	.6606	.6534	.6532	.1401	.1402	.1565	.1564	.6569	—.0003	.1483	.0009	.0003	.0056
45,500	.6599	.6597	.6521	.6520	.1447	.1446	.1609	.1607	.6559	—.0010	.1527	.0044	.0017	.0073
50,500	.6675	.6677	.6598	.6600	.1409	.1408	.1561	.1559	.6637	.0078	.1484	.0043	.0017	.0090
55,500	.6680	.6682	.6604	.6606	.1415	.1417	.1568	.1566	.6643	.0006	.1491	.0007	.0007	.0097
60,500	.6696	.6697	.6622	.6624	.1441	.1439	.1590	.1590	.6659	.0016	.1515	.0024	.0020	.0117
65,500	.6696	.6698	.6622	.6622	.1485	.1487	.1639	.1638	.6660	.0001	.1562	.0047	.0024	.0141
70,500	.6702	.6702	.6626	.6628	.1560	.1558	.1704	.1707	.6664	.0004	.1632	.0070	.0037	.0178
75,500	.6721	.6723	.6640	.6639	.1806	.1804	.1945	.1945	.6681	.0017	.1875	.0243	.0130	.0308
	Load dropped off 21 hours.													
75,500	.6450	.6449	.6359	.6357	.2341	.2343	.2428	.2428	.6404	....	.2385	....	....	....
80,500	.6385	.6387	.6298	.6296	.2535	.2533	.2625	.2626	.6341	—.0063	.2579	.0194	.0065	.0373
85,500	.6311	.6312	.6209	.6201	.2749	.2747	.2845	.2844	.6256	—.0085	.2796	.0217	.0066	.0439
90,500	.6148	.6149	.6063	.6064	.3244	.3244	.3336	.3335	.6106	—.0150	.3290	.0494	.0172	.0611
95,500	.6132	.6132	.6050	.6051	.3313	.3314	.3404	.3403	.6091	—.0015	.3358	.0068	.0026	.0637
100,500	.6044	.6045	.5967	.5966	.3590	.3592	.3700	.3700	.6005	—.0086	.3645	.0288	.0101	.0738
105,500	.5910	.5910	.5826	.5825	.4019	.4019	.4112	.4111	.5868	—.0137	.4065	.0419	.0141	.0879
110,500	.5839	.5840	.5757	.5757	.4262	.4262	.4349	.4350	.5798	—.0070	.4306	.0241	.0085	.0964
115,500	.5780	.5782	.5697	.5698	.4482	.4480	.4564	.4563	.5739	—.0059	.4522	.0216	.0078	.1042
120,500	.5709	.5708	.5621	.5620	.4746	.4746	.4833	.4835	.5664	—.0075	.4790	.0268	.0096	.1138
125,500	.5597	.5595	.5500	.5498	.5163	.5162	.5226	.5225	.5547	—.0117	.5194	.0404	.0143	.1281
130,500	.5544	.5543	.5471	.5470	.5412	.5413	.5500	.5499	.5507	—.0040	.5456	.0262	.0111	.1392
135,500	.5530	.5532	.5457	.5457	.5532	.5532	.5619	.5618	.5494	—.0013	.5575	.0119	.0053	.1445
140,500	.5574	.5572	.5489	.5488	.5791	.5792	.5875	.5874	.5531	+.0037	.5833	.0258	.0147	.1592
145,500	.5561	.5561	.5471	.5470	.6061	.6062	.6137	.6135	.5516	—.0016	.6099	.0266	.0125	.1717
150,500	.5670	.5672	.5575	.5576	.6319	.6320	.6374	.6374	.5623	+.0107	.6347	.0248	.0177	.1894
155,500	.5857	.5859	.5760	.5760	.6514	.6514	.6561	.6562	.5809	+.0186	.6538	.0191	.0188	.2082
160,500	.6055	.6055	.5951	.5953	.6729	.6730	.6790	.6790	.6003	+ 194	.6760	.0222	.0208	.2290
225,500	Maximum load. (Joint gave way by plate tearing.)													

Size of bolts	$1\frac{1}{8}$″	Maximum tension per sq. in. on net section of plate	58,100 lbs.
Pitch of bolts	4″	Maximum shear per sq. in. on bolts	37,600 lbs.
Thickness of plate	.45″	Maximum compression per sq. in. on plate,	148,600 lbs.
Width of plate	12.00″	Av. thickness of plate in front of bolts at fracture	.56″
Area net section of plate	3.88 sq. in.	Reduction of area of net section of plate,	26%
Bolts were set up with 60 lbs. pull on 13-in. wrench.		Efficiency of joint	62%

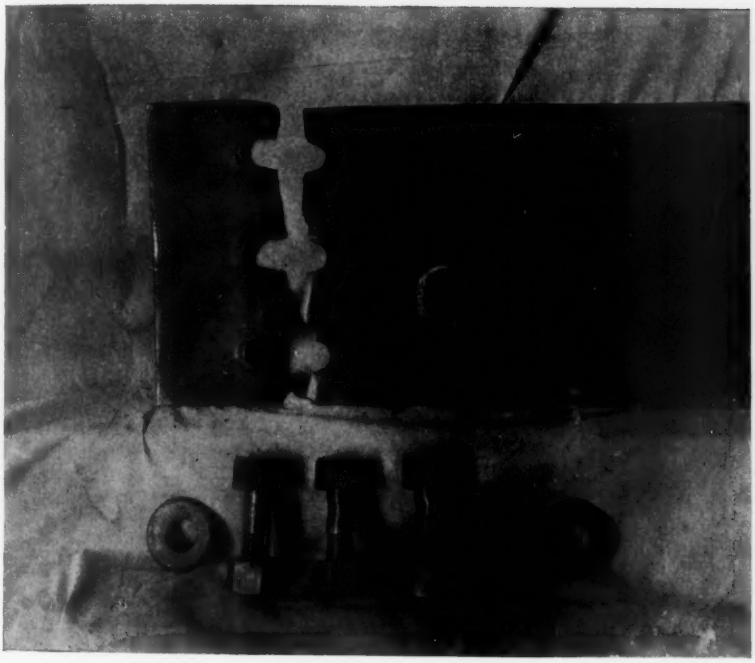


FIG. 9. BOLTED JOINT, NO. 8.

TENSION TEST. No. 21.

Specimen, Steel Boiler Plate. Date, December 12, 1895.

Loads.	Micrometer Readings.				Mean.	Differences.
Actual.	1	2	1	2		Actual.
500	.3368	.3368	.4003	.4003	.3686	....
3,500	.3390	.3391	.4012	.4012	.3701	.0015
6,500	.3408	.3408	.4025	.4023	.3716	.0015
500	.3396	.3398	.3988	.3988	.3692	.0024
14,000	.3442	.3443	.4049	.4051	.3746	....
15,000	.3447	.3448	.4052	.4054	.3750	.0004
16,000	.3451	.3452	.4058	.4059	.3755	.0005
17,000	.3457	.3458	.4062	.4061	.3760	.0005
18,000	.3463	.3464	.4066	.4066	.3764	.0004
19,000	.3469	.3470	.4074	.4072	.3771	.0007
20,000	.3472	.3473	.4077	.4078	.3775	.0004
21,000	.3478	.3477	.4086	.4087	.3782	.0007
22,000	.3485	.3487	.4102	.4102	.3794	.0012
23,000	.3494	.3493	.4123	.4125	.3809	.0015

Length between clamps	8″	Area of original section; sq. ins.	.649
Dimensions of cross section	.43″ x 1.51″	Elastic limit; lbs. per sq. in.	27,700
Elastic limit	18,000 lbs.	Maximum load; lbs. per sq. in. orig. sect.	69,200
Maximum load	44,930 lbs.	Area of fractured section; sq. in.	.328
Dimensions of fractured section	.29″ x 1.13″	Reduction of area of cross section; per cent.,	49.5
Ultimate extension	1.87″	Ultimate extension; per cent.	23.4
Elastic elongation for 6,000 lbs. load equals	.0024″	Modulus of elasticity	30,800,000

TENSION TEST. No. 22.

Specimen, Boiler Plate. Date, December 13, 1895.

Loads.	Micrometer Readings.				Mean.	Differences.
Actual.	1	2	1	2		Actual.
500	.3730	.3731	.4116	.4116	.3923	....
3,500	.3748	.3750	.4126	.4126	.3937	.0014
6,500	.3755	.3757	.4138	.4138	.3947	.0010
14,000	.3784	.3786	.4168	.4169	.3977	....
16,000	.3795	.3795	.4176	.4176	.3985	.0008
18,000	.3803	.3804	.4185	.4186	.3994	.0009
20,000	.3818	.3817	.4196	.4196	.4007	.0013
22,000	.3836	.3837	.4212	.4212	.4024	.0017
24,000	.3878	.3878	.4252	.4253	.4065	.0041

Length between clamps	8″	Area of original section; sq. ins.	.680
Dimensions of cross section	1.51″ x .45″	Elastic limit; lbs. per sq. in.	26,500
Elastic limit	18,000 lbs.	Maximum load; lbs. per sq. in. orig. sect.	65,500
Maximum load	44,500 lbs.	Area of fractured section; sq. in.	.339
Dimensions of fractured section	1.13″ x .30″	Reduction of area of cross section; per cent.,	50.1
Ultimate extension	1.69″	Ultimate extension; per cent.	21.1
Elastic elongation for 6,000 lbs. load equals	.0024″	Modulus of elasticity	29,400,000

TENSION TEST. No. 23.

Specimen, Steel Boiler Plate. Date, December 31, 1895.

Loads.	Micrometer Readings.				Mean.	Differences.
Actual.	1	2	1	2		Actual.
500	.4193	.4193	.3806	.3805	.3999	....
6,500	.4216	.4217	.3833	.3832	.4025	.0026
500	.4194	.4195	.3807	.3806	.4001	.0024
15,000	.4249	.4248	.3871	.3870	.4060	....
16,000	.4254	.4253	.3873	.3874	.4064	.0004
17,000	.4257	.4257	.3879	.3878	.4068	.0004
18,000	.4260	.4260	.3883	.3882	.4071	.0003
19,000	.4263	.4265	.3887	.3885	.4075	.0004
20,000	.4270	.4268	.3890	.3891	.4080	.0005
21,000	.4273	.4272	.3899	.3898	.4086	.0006
22,000	.4279	.4279	.3907	.3907	.4193	.0007
23,000	.4288	.4286	.3916	.3915	.4101	.0008
24,000	.4294	.4294	.3927	.3926	.4110	.0009
25,000	.4305	.4305	.3942	.3943	.4124	.0014

Length between clamps	8″	Area of original section; sq. ins.	.660
Dimensions of cross section	0.44″ x 1.50″	Elastic limit; lbs. per sq. in.	28,800
Elastic limit	19,000 lbs.	Maximum load; lbs. per sq. in. orig. sect.	69,700
Maximum load	46,000 lbs.	Area of fractured section; sq. in	.396
Dimensions of fractured section	0.33″ x 1.20″	Reduction of area of cross section; per cent.,	40.0
Ultimate extension	1.69″	Ultimate extension; per cent.	21.1
Elastic elongation for 6,000 lbs. load equals	.0024″	Modulus of elasticity	30,300,000

TENSION TEST. No. 30.

Specimen, Bolt Steel. Date, March 6, 1896.

Loads.	Micrometer Readings.				Mean.	Differences.
Actual.	1	2	1	2		Actual.
500	.4339	.4338	.0196	.0196	.2267	....
3,500	.4366	.4368	.0215	.0213	.2291	.0023
6,500	.4390	.4390	.0237	.0237	.2314	.0023
19,000	.4452	.4453	.0330	.0331	.2391	....
20,000	.4493	.4493	.0342	.0340	.2417	.0026
21,000	.4504	.4503	.0347	.0349	.2426	.0009
22,000	.4504	.4504	.0358	.0358	.2431	.0005
23,000	.4515	.4513	.0370	.0370	.2442	.0011
24,000	.4521	.4520	.0378	.0380	.2449	.0007
25,000	.4523	.4521	.0396	.0396	.2459	.0010
26,000	.4532	.4528	.0411	.0411	.2470	.0011
27,000	Piece would not hold load.					

Length between clamps	10″	Area of original section; sq. ins.	.443
Dimension of cross section	.7509″ dia.	Elastic limit; lbs. per sq. in.	58,700
Elastic limit	26,000 lbs.	Maximum load; lbs. per sq. in. orig. sect.	94,400
Maximum load	41,800 lbs.	Area of fractured section; sq. in.	.221
Dimension of fractured section	.5310″ dia.	Reduction of area of cross section; per cent.,	50.0
Ultimate extension	2.06″	Ultimate extension; per cent.	20.6
Elastic elongation for 6,000 lbs. load equals,	.0046″	Modulus of elasticity	29,500,000

TENSION TEST. No. 31.

Specimen, Bolt Steel. Date, March 7, 1896.

Loads. Actual.	Micrometer Readings. 1	2	1	2	Mean.	Differences. Actual.
500	—.0062	—.0063	—.0156	—.0157	—.0110	....
3,500	—.0033	—.0034	—.0139	—.0141	—.0087	.0023
6,500	—.0015	—.0015	—.0116	—.0114	—.0065	.0023
20,000	—.0003	—.0004	+.0081	+.0081	+.0039	....
21,000	+.0087	+.0087	+.0009	+.0008	+.0048	.0009
22,000	+.0091	+.0089	+.0020	+.0022	+.0056	.0008
23,000	+.0095	+.0094	+.0034	+.0036	+.0065	.0009
24,000	+.0101	+.0100	+.0048	+.0048	+.0074	.0009
25,000	+.0106	+.0109	+.0063	+.0060	+.0084	.0010
26,000	+.0112	....	+.0079	....	+.0095	.0011
27,000	Piece would not hold load.					

Length between clamps	10″	Area of original section; sq. ins.	.441
Dimension of cross section	.7495″ dia.	Elastic limit; lbs. per sq. in.	58,900
Elastic limit	26,000 lbs.	Maximum load; lbs. per sq. in. orig. sect.,	99,300
Maximum load	43,800 lbs.	Area of fractured section; sq. in.	.215
Dimension of fractured section	.5237″ dia.	Reduction of area of cross section; per cent.,	51.2
Ultimate extension	2.12″	Ultimate extension; per cent.	21.2
Elastic elongation for 6,000 lbs. load equals,	.0046″	Modulus of elasticity	29,600,000

TENSION TEST. No. 32.

Specimen, Bolt Steel. Date, March 11, 1896.

Loads. Actual.	Micrometer Readings. 1	2	1	2	Mean.	Differences. Actual.
500	.0402	.0403	—.0164	—.0165	.0119	....
3,500	.0427	.0426	—.0143	—.0145	.0141	.0022
6,500	.0448	.0447	—.0117	—.0118	.0165	.0024
20,000	.0564	.0564	—.0019	—.0018	.0273	....
21,000	.0574	.0574	—.0016	—.0016	.0279	.0006
22,000	.0588	.0586	—.0012	—.0011	.0288	.0009
23,000	.0596	.0595	—.0003	—.0005	.0296	.0008
24,000	.0603	.0603	+.0002	+.0002	.0303	.0007
25,000	.0612	.0612	+.0014	+.0014	.0313	.0010
26,000	Piece would not hold the load.					

Length between clamps	10″	Area of original section; sq. ins.	.441
Dimension of cross section	.749″ dia.	Elastic limit; lbs. per sq. in.	56,700
Elastic limit	25,000 lbs.	Maximum load; lbs. per sq. in. orig. sect.	95,100
Maximum load	41,890 lbs.	Area of fractured section; sq. in.	.219
Dimension of fractured section	.528″ dia.	Reduction of area of cross section; per cent.,	50.3
Ultimate extension	2.06″	Ultimate extension; per cent.	20.6
Elastic elongation for 6,000 lbs. load equals,	.0046″	Modulus of elasticity	29,600,000

Tests on Bolted Joints. (Boston Bridge Works.)

These joints were furnished by the Boston Bridge Works, and were designed to show the efficiency of a rough bolted joint. The form of the joints is indicated by the cut. From one to four bolts were used on each side of the joint, the bolts being placed in line as shown in the sketch. These bolts were all rough forged iron bolts of standard dimensions. The holes in the plate were punched, making a loose fit for the bolts. All the nuts were set up hard before breaking. Both one and two battens were used on each style of joint. When thin plate is used, the shearing strength of the bolts is figured on the nominal area, corresponding to the nominal diameter of the bolts, and the effective area figured on the diameter at the bottom of the threads, this being the area to resist the shear when a thin plate and cover strips are used.

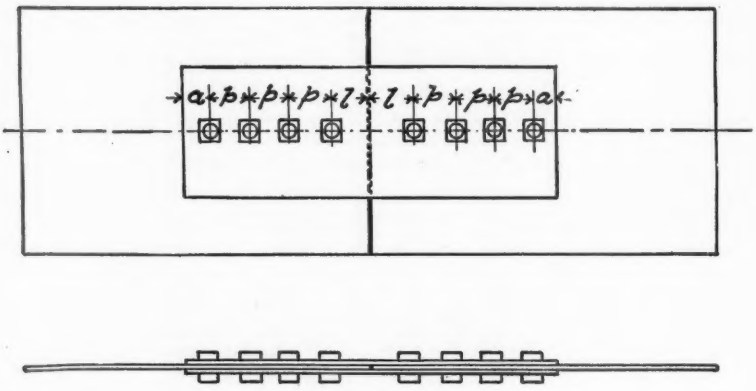


Fig. 10. Form of Bolted Joint.

TESTS ON BOLTED JOINTS. (BOSTON BRIDGE WORKS.)

No. of test.	No. of joint.	Diameter of bolts. (Inches.)	Number of bolts.	A. (Inches.)	l. (Inches.)	a. (Inches.)	Thickness of plate. (Inches.)	Width of plate. (Inches.)	No. of battens.	Thickness of battens. (Inches.)	Width of battens. (Inches.)	Length of battens. (Inches.)	Maximum load.	Maximum shear on bolts. Nominal area. (Lbs. per sq. in.)	Maximum shear on bolts. Effective area. (Lbs. per sq. in.)	Maximum shear on plate. (Lbs. per sq. in.)	Maximum compression in front of bolts. (Lbs. per sq. in.)	Manner of breaking.
1	1		1	..	1½	1½		2½	1		2½	6	9,000	29,300	44,600	12,000	57,600	Bolt sheared.
2	1		1	..	1½	1½		2½	1		2½	6	10,100	32,900	50,000	13,500	64,600	Bolt sheared.
3	2		1	..	1½	1½		4½	2		2½	6	19,700	32,100	48,800	26,300	126,000	Bolt sheared.
4	2		1	..	1½	1½		4½	2		2½	6	17,800	29,000	44,100	23,700	114,000	Bolt sheared.
5	3		4	2	2½	1½		8	1		8	23	31,000	25,300	38,400	6,200	49,600	Bolts sheared.
6	3		4	2	2½	1½		8	1		8	23	35,000	28,500	43,300	7,000	56,000	Bolts sheared.
7	4		4	2	2½	1½		15½	2		8	23	66,200	27,000	41,000	13,200	105,900	Bolts sheared.
8	4		4	2	2½	1½		15½	2		8	23	68,800	28,000	42,600	13,800	110,100	Bolts sheared.
9	5		1	..	1½	1½		4½	1		4½	6	15,800	26,300	37,600	21,100	72,200	Bolt sheared.
10	5		1	..	1½	1½		4½	1		4½	6	17,600	29,300	41,900	23,500	80,500	Bolt sheared.
11	6		1	..	1½	1½		8	2		4½	6	20,400	17,000	24,300	27,200	93,300	Plate sheared in front of bolt.
12	6		1	..	1½	1½		8	2		4½	6	19,700	16,400	23,500	26,300	90,100	Plate sheared in front of bolt.
13	7		4	3	3	1½		15½	1		15½	27	69,000	28,700	41,100	11,500	78,900	Bolts sheared.
14	7		4	3	3	1½		15½	1		15½	27	71,000	29,500	42,300	11,800	81,100	Bolts sheared.
15	8		4	3	3	1½		18	2		10½	27	145,100	30,200	43,200	16,100	110,500	Bolts sheared.
16	8		4	3	3	1½		18	2		10½	27	147,300	30,600	43,800	18,700	112,200	Bolts sheared.
17	9		1	..	1½	1½		2	1		2	6	5,600	18,200	....	2,500	11,900	Bolt sheared.
18	9		1	..	1½	1½		2	1		2	6	11,600	37,800	....	5,200	24,700	Bolt sheared.
19	10		1	..	1½	1½		2	2		2	6	13,300	21,700	....	5,900	28,400	Bolt sheared.
20	10		1	..	1½	1½		2	2		2	6	14,700	23,900	....	6,500	31,400	Bolt sheared.
21	11		4	2½	2½	1½		3½	1		3½	23	40,100	32,700	....	2,700	21,400	Bolts sheared.
22	11		4	2½	2½	1½		3½	1		3½	23	44,800	36,500	....	3,000	23,900	Bolts sheared.
23	12		4	2½	2½	1½		5½	2		3½	23	79,000	32,500	....	5,800	42,100	Bolts sheared.
24	12		4	2½	2½	1½		5½	2		3½	23	79,700	32,800	....	5,900	42,600	Bolts sheared.
25	13		1	..	3	1½		3½	1		2½	9	19,700	32,800	....	4,400	30,000	Batten broke by tension through bolt hole.
26	13		1	..	3	1½		2½	1		2½	9	25,000	41,600	....	5,600	38,100	Bolt sheared.
27	14		1	..	3	1½		3½	2		2½	9	38,800	32,300	....	8,600	59,100	Bolts sheared.
28	14		1	..	3	1½		3½	2		2½	9	38,000	31,600	....	8,400	57,900	Bolt sheared.
29	15		4	3	3	1½		6	1		6	27	79,900	33,200	....	4,400	30,400	Bolts sheared.
30	15		4	3	3	1½		6	1		6	27	78,500	32,600	....	4,400	29,900	Bolts sheared.
31	16		4	3	3	1½		10½	2		6	27	161,000	33,500	....	10,200	61,300	Bolts sheared.
32	16		4	3	3	1½		10½	2		6	27	145,400	30,200	....	9,200	55,400	Bolts sheared.

Wrought Iron Pipe Columns.

SUMMARY OF TESTS.

Date of Test.	Nominal size of pipe.	Inside diameter.	Outside diameter.	Diameter of flanges.	Length of inside of flanges.	Gauge length.	Maximum load.	Area of cross section.	Maximum load per sq. in.	Compression. Modulus of elasticity.	$\frac{l}{\rho}$, or ratio of length to radius of gyration.
	In.	In.	In.	In.	In	In.	Lbs.	Sq. in.	Lbs.		
March 31, 1896	2	2.06	2.37	7	6 9/16	51	30,000	1.08	27,800	24,300,000	88.8
" 30 "	2	2.04	2.39	7	6 9/16	51	29,800	1.22	24,500	22,200,000	89.1
" 26 "	2½	2.50	2.89	8	9 3/16	86	34,500	1.65	20,900	25,200,000	98.1
" 27 "	2½	2.48	2.88	8	9 3/16	86	37,000	1.68	22,000	25,900,000	98.4
" 10 "	3	3.06	3.44	8½	9 3/16	86	45,500	1.94	23,500	27,700,000	81.4
" 12 "	3	3.09	3.48	8½	9 3/16	86	51,000	2.01	25,300	25,100,000	80.5
" 24 "	3½	3.60	4.00	9½	10 5/16	100.5	55,000	2.39	23,000	25,200,000	78.2
" 25 "	3½	3.59	3.99	9½	10 5/16	100.5	65,000	2.39	27,200	24,600,000	78.5
" 16 "	4	4.07	4.53	9½	11 7/16	100.5	80,000	3.11	25,700	25,800,000	77.1
" 20 "	4	4.09	4.50	9½	11 7/16	100.5	69,000	2.76	25,000	24,900,000	77.3

These were tested in the same manner as the spruce columns already described in Technology Quarterly, Vol. 8, pp. 219–247, 1895.

TEST OF WROUGHT IRON PIPE COLUMN.

Date, March 31, 1896.

Loads.	North Side. Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.	South Side. Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.	Average difference of micrometer readings.	Average difference of abscissæ.	Average difference of ordinates.
5,000	.9466	.94670	.....	.55	.44	.6575	.65745	....	.32	.32	.....	.....	.....
	.9468					.6574							
7,500	.9423	.94240	.0043	.55	.44	.6521	.65210	.0054	.32	.32	.00485	.000	.000
	.9425					.6521							
10,000	.9375	.93745	.0050	.55	.45	.6473	.64730	.0048	.31	.32	.00490	—.005	.005
	.9374					.6473							
12,500	.9330	.93300	.0045	.55	.45	.6430	.64295	.0044	.31	.32	.00445	.000	.000
	.9330					.6429							
15,000	.9275	.92740	.0056	.55	.45	.6383	.63825	.0047	.31	.32	.00515	.000	.000
	.9273					.6382							
17,500	.9220	.92190	.0055	.55	.45	.6342	.63430	.0040	.31	.32	.00475	.000	.000
	.9218					.6344							
20,000	.9158	.91575	.0062	.55	.45	.6301	.63005	.0043	.31	.32	.00525	.000	.000
	.9157					.6300							
22,500	.9102	.91020	.0056	.57	.41	.6240	.62405	.0060	.33	.28	.00580	.020	—.040
	.9102					.6241							
25,000	.9043	.90440	.0058	.54	.36	.6188	.61875	.0053	.33	.25	.00555	—.015	—.040
	.9045					.6187							
27,500	.....	.....	.....	.54	.36	.....	.....	....	.33	.25	.....	.000	.000

Nominal size of pipe	2″	Compression (5,000–15,000)	.0194″
Actual inside diameter	2.06″	Area of cross section	1.08 sq. in.
Actual outside diameter	2.37″	Maximum load	27,800 lbs. per sq. in.
Length inside of flanges	6 9/16″	Modulus of elasticity (5,000–15,000)	24,300,000
Diameter of flanges	7″	$\frac{l}{\rho}$	88.8
Gauge length	51″		
Maximum load	30,000 lbs.		

TEST OF WROUGHT IRON PIPE COLUMN.

Date, March 30, 1896.

Loads.	North Side.					South Side.					Average difference of micrometer readings.	Average difference of abscissæ.	Average difference of ordinates.
	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.			
5,000	.7139	.7138	.....	.30	.42	.7985	.7985	.....	.33	.45	.....	....	....
	.7137					.7985							
7,500	.7089	.7089	.0049	.30	.42	.7927	.7927	.0058	.33	.45	.00535	.000	.000
	.7088					.7927							
10,000	.7043	.7044	.0045	.30	.42	.7888	.7889	.0038	.33	.45	.00415	.000	.000
	.7044					.7889							
12,500	.6995	.6995	.0049	.30	.42	.7841	.7842	.0047	.33	.45	.00480	.000	.000
	.6995					.7842							
15,000	.6953	.6953	.0042	.30	.42	.7792	.7793	.0049	.33	.45	.00455	.000	.000
	.6952					.7794							
17,500	.6908	.6909	.0044	.30	.42	.7742	.7742	.0051	.33	.45	.00475	.000	.000
	.6909					.7742							
20,000	.6879	.6879	.0030	.30	.42	.7682	.7681	.0061	.32	.45	.00455	—.005	.000
	.6878					.7680							
22,500	.6857	.6857	.0022	.28	.42	.7632	.7631	.0050	.30	.45	.00360	—.020	.000
	.6857					.7630							
25,000	.6836	.6835	.0022	.26	.41	.7542	.7543	.0088	.29	.45	.00550	—.015	—.005
	.6835					.7544							
27,500	.....	.....	.....	.24	.41	.....	.....	.....	.26	.44	.....	— 025	— 005

Nominal size of pipe	2″	Maximum load	29,800 lbs.
Actual inside diameter	2.04″	Compression (5,000-15,000)	.01885″
Actual outside diameter	2.39″	Area of cross section	1.22 sq. in.
Length inside of flanges	$69\frac{1}{16}$″	Maximum load	24,500 lbs. per sq. in.
Diameter of flanges	7″	Modulus of elasticity	22,200,000
Gauge length	51″	$\frac{l}{\rho}$	89.1

TEST OF WROUGHT IRON PIPE COLUMN.

Date, March 26, 1896.

Loads.	North Side.					South Side.					Average difference of micrometer readings.	Average difference of abscissæ.	Average difference of ordinates.
	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.			
5,000	.5742 .5743	.5743	.....	.60	.67	.4117 .4116	.4117	.....	.40	.60	.....	.....	....
10,000	.5660 .5660	.5660	.0085	.58	.67	.3999 .4000	.4000	.0117	.40	.60	.01000	—.010	.000
15,000	.5584 .5586	.5585	.0075	.57	.68	.3873 .3871	.3872	.0128	.38	.62	.01015	—.015	.015
20,000	.5502 .5500	.5501	.0084	.56	.68	.3740 .3738	.3739	.0133	.37	.63	.01085	—.010	.005
25,000	.5401 .5403	.5402	.0099	.56	.68	.3618 .3620	.3619	.0120	.36	.65	.01095	—.005	.010
30,000	.5273 .5271	.5272	.0130	.55	.73	.3483 .3483	.3483	.0136	.35	.65	.01330	—.010	.035

Nominal size of pipe	2½″	Maximum load	34,500 lbs.
Actual inside diameter	2.50″	Compression (5,000–20,000)	0.0310″
Actual outside diameter	2.89″	Area of cross section	1.65 sq. in.
Length inside of flanges	93$\frac{11}{16}$″	Maximum load	20,900 lbs. per sq. in.
Diameter of flanges	8″	Modulus of elasticity	25,200,000
Gauge length	86″	$\frac{l}{\rho}$	98.1

TEST OF WROUGHT IRON PIPE COLUMN.

Date, March 27, 1896.

Loads.	North Side.					South Side.					Average difference of micrometer readings.	Average difference of abscissæ.	Average difference of ordinates.
	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.			
5,000	.4060 .4061	.4061	....	.17	.20	.6430 .6428	.6429	.....	.40	.37	.....	.....	.....
10,000	.4002 .4002	.4002	.0059	.16	.17	.6302 .6300	.6301	.0128	.39	.30	.00935	—.010	—.050
15,000	.3911 .3912	.3912	.0090	.16	.16	.6191 .6191	.6191	.0110	.38	.29	.01000	—.005	—.010
20,000	.3811 .3811	.3811	.0101	.16	.15	.6086 .6085	.6086	.0105	.38	.27	.01030	.000	—.015
25,000	.3737 .3739	.3738	.0073	.15	.15	.5944 .5945	.5945	.0141	.36	.27	.01070	—.015	.000
30,000	.3636 .3635	.3636	.0102	.15	.15	.5840 .5840	.5840	.0105	.36	.26	.01035	.000	—.005
35,000	.....	.....	.....	.13	.15	.....	.....	.....	.34	.25	.....	—.020	—.005

Nominal size of pipe	2½″	Maximum load	37,000 lbs.
Actual inside diameter	2.48″	Compression (5,000–20,000)	.0297″
Actual outside diameter	2.88″	Area of cross section	1.68 sq. in.
Length inside of flanges	93½″	Maximum load	22,000 lbs. per sq. in.
Diameter of flanges	8″	Modulus of elasticity	25,900,000
Gauge length	86″	$\frac{l}{\rho}$	98.4

TEST OF WROUGHT IRON PIPE COLUMN.

Date, March 10, 1896.

Loads.	North Side.					South Side.					Average difference of micrometer readings.	Average difference of abscissæ.	Average difference of ordinates.
	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.			
1,500	1.0283 1.0285	1.0284	.....	.20	.40	.6748 .6748	.6748	.....	25	.37	.....	.....	.....
3,500	1.0286 1.0284	1.0285	—.0001	.16	.40	.6679 .6681	.6680	.0068	.20	.29	.00335	—.045	—.040
5,500	1.0245 1.0245	1.0245	.0040	.17	.40	.6636 .6636	.6636	.0044	.21	.29	.00420	.010	.000
7,500	1.0221 1.0219	1.0220	.0025	.16	.39	.6594 .6596	.6595	.0041	.20	.28	.00330	—.010	—.010
7,500	1.0223 1.0225	1.0224	.....	.17	.37	.6608 .6609	.6609	.....	.21	.28	.....	.010	—.010
9,500	1.0196 1.0195	1.0196	.0028	.16	.37	.6569 .6567	.6568	.0041	.21	.26	.00345	—.005	—.010
11,500	1.0170 1.0168	1.0169	.0027	.15	.37	.6530 .6529	.6530	.0038	.20	.25	.00325	—.010	—.005
13,500	1.0139 1.0140	1.0140	.0029	.15	.37	.6492 .6492	.6492	.0038	.20	.24	.00335	.000	—.005
15,500	1.0108 1.0110	1.0109	.0031	.15	.37	.6453 .6454	.6454	.0038	.20	.24	.00345	.000	.000
17,500	1.0079 1.0078	1.0079	.0030	.15	.37	.6416 .6415	.6416	.0038	.20	.24	.00340	.000	.000
19,500	1.0048 1.0049	1.0049	.0030	.15	.37	.6378 .6380	.6379	.0037	.20	.24	.00335	.000	.000
21,500	1.0016 1.0014	1.0015	.0034	.15	.36	.6341 .6342	.6342	.0037	.19	.24	.00355	—.005	—.005
24,000	.9969 .9970	.9970	.0045	.15	.36	.6298 .6299	.6299	.0043	.19	.24	.00440	.000	.000
26,500	.9933 .9935	.9934	.0036	.15	.36	.6251 .6252	.6252	.0047	.19	.23	.00415	.000	—.005
29,000	.9889 .9889	.9889	.0045	.15	.36	.6201 .6203	.6202	.0050	.19	.21	.00425	.000	—.010
31,500	.9855 .9854	.9855	.0034	.14	.36	.6153 .6151	.6152	.0050	.19	.21	.00420	—.005	.000
33,000	.9839 .9839	.9839	.0016	.14	.36	.6120 .6118	.6119	.0033	.18	.21	.00245	—.005	.000
35,500	.9792 .9793	.9793	.0046	.14	.35	.6068 .6070	.6069	.0050	.17	.20	.00480	—.005	—.010
38,000	.9750 .9749	.9750	.0043	.14	.34	.6010 .6011	.6011	.0058	.16	.20	.00505	—.005	—.005
40,500	.9711 .9710	.9711	.0039	.13	.33	.5935 .5934	.5935	.0076	.16	.21	.00575	—.005	.000
43,000	.9672 .9672	.9672	.0039	.12	.32	.5840 .5840	.5840	.0095	.15	.19	.00670	—.010	—.015

Nominal size of pipe	3″	Maximum load	45,500 lbs.
Actual inside diameter	3.06″	Compression (4,500-14,500)	.0160″
Actual outside diameter	3.44″	Area of cross section	1.94 sq. in.
Length inside of flanges	$93\frac{3}{8}$″	Maximum load	23,500 lbs. per sq. in.
Diameter of flanges	$8\frac{1}{2}$″	Modulus of elasticity	27,700,000
Gauge length	86″	$\frac{l}{\rho}$	81.4

TEST OF WROUGHT IRON PIPE COLUMN.

Date, March 12, 1896.

Loads.	North Side.					South Side.					Average difference of micrometer readings.	Average difference of abscissæ.	Average difference of ordinates.
	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.			
2,500	.3190	.3191	.....	.16	.28	.4520	.4521	.....	.26	.33	.....	.....	.....
	.3192					.4522							
5,000	.3115	.3115	.0076	.19	.26	.4533	.4522	.0001	.28	.30	.00385	.025	—.025
	.3115					.4521							
7,500	.3053	.3053	.0062	.20	.25	.4487	.4486	.0036	.29	.29	.00490	.010	—.010
	.3053					.4485							
10,000	.2995	.2996	.0057	.21	.25	.4458	.4457	.0029	.29	.28	.00430	.005	—.005
	.2996					.4456							
12,500	.2989	.2989	.0007	.22	.25	.4431	.4432	.0025	.30	.28	.00160	.010	.000
	.2988					.4433							
15,000	.2882	.2883	.0106	.22	.25	.4400	.4401	.0031	.30	.28	.00665	.000	.000
	.2884					.4402							
17,500	.2836	.2836	.0047	.23	.25	.4362	.4361	.0041	.31	.27	.00440	.010	—.005
	.2836					.4360							
20,000	.2794	.2793	.0043	.23	.25	.4319	.4320	.0041	.31	.27	.00420	.000	.000
	.2792					.4321							
22,500	.2749	.2750	.0043	.23	.25	.4279	.4280	.0040	.31	.27	.00415	.000	.000
	.2750					.4281							
25,000	.2708	.2708	.0042	.22	.25	.4232	.4232	.0048	.31	.29	.00450	—.005	.010
	.2708					.4231							
27,500	.2665	.2664	.0044	.22	.26	.4195	.4192	.0040	.31	.28	.00420	.000	.000
	.2663					.4193							
30,000	.2620	.2620	.0044	.23	.26	.4140	.4140	.0052	.31	.28	.00480	.005	.000
	.2619					.4139							
32,500	.2575	.2574	.0046	.23	.26	.4107	.4106	.0034	.31	.29	.00400	.000	.005
	.2573					.4105							
35,000	.2533	.2533	.0041	.23	.26	.4062	.4063	.0043	.31	.29	.00420	.000	.000
	.2533					.4064							
37,500	.2447	.2448	.0085	.24	.27	.4032	.4031	.0032	.32	.30	.00585	.010	.010
	.2448					.4034							
40,000	.2380	.2379	.0069	.25	.28	.4004	.4004	.0027	.33	.30	.00480	.010	.005
	.2378					.4004							
42,500	.2334	.2334	.0045	.25	.28	.3964	.3964	.0040	.33	.30	.00425	.000	.000
	.2333					.3964							
45,000	.2266	.2265	.0069	.26	.27	.3931	.3931	.0033	.34	.31	.00510	.010	.000
	.2264					.3931							
47,500	....	....	.....	.29	.28	.....	....	....	.36	.31	.....	.025	.005
50,000	.....	....	.....	.70	.30	.....	....	....	.02	.31	.....	.335	.010

Nominal size of pipe	3″	Maximum load	51,000 lbs.
Actual inside diameter	3.09″	Compression (2,500-22,500)	.0341″
Actual outside diameter	3.48″	Area of cross section	2.01 sq. in.
Length inside of flanges	93⅝″	Maximum load	25,300 lbs. per sq. in.
Diameter of flanges	8¾″	Modulus of elasticity	25,100,000
Gauge length	86″	$\frac{l}{\rho}$	80.5

TEST OF WROUGHT IRON PIPE COLUMN.

Date, March 24, 1896.

Loads.	North Side.					South Side.					Average difference of micrometer readings.	Average difference of abscissæ.	Average difference of ordinates.
	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.			
5,000	.3700	.3669	.....	.30	.44	.2288	.2289	.....	.23	.32	.....	.....	.....
	.3668					.2290							
10,000	.3626	.3627	.0042	.30	.44	.2189	.2188	.0101	.22	.30	.00715	—.005	—.010
	.3628					.2186							
15,000	.3538	.3529	.0098	.30	.44	.2107	.2107	.0081	.22	.30	.00895	.000	.000
	.3520					.2108							
20,000	.3437	.3444	.0085	.30	.41	.2015	.2015	.0092	.22	.30	.00885	.000	—.015
	.3450					.2014							
25,000	.3373	.3370	.0074	.30	.40	.1929	.1928	.0087	.22	.29	.00805	.000	—.010
	.3368					.1928							
30,000	.3293	.3290	.0080	.30	.40	.1843	.1843	.0085	.22	.28	.00825	.000	—.005
	.3287					.1843							
35,000	.3198	.3198	.0092	.30	.40	.1757	.1757	.0086	.22	.28	.00890	.000	.000
	.3199					.1757							
40,000	.3114	.3115	.0083	.30	.38	.1662	.1662	.0095	.22	.26	.00890	.000	—.020
	.3115					.1662							
45,000	.3007	.3008	.0107	.30	.27	.1463	.1463	.0199	.20	.16	.01530	—.010	—.105
	.3009					.1462							
50,000	.....	.....	.....	.30	.27	.....	.....	.....	.20	.16	.....	.000	.000
55,000	.....	.....	.....	.29	.17	.....	.....	.....	.20	.06	.....	—.005	—.010

Nominal size of pipe	$3\frac{1}{2}''$	Maximum load	55,000 lbs.
Actual inside diameter	$3.60''$	Compression (5,000–35,000),	$.05015''$
Actual outside diameter	$4.00''$	Area of cross section	2.39 sq. in.
Length inside of flanges	$105\frac{1}{4}''$	Maximum load	23,000 lbs. per sq in.
Diameter of flanges	$9\frac{1}{2}''$	Modulus of elasticity	25,100,000 lbs.
Gauge length	$100.5''$	$\frac{l}{\rho}$	78.2

TEST OF WROUGHT IRON PIPE COLUMN.

Date, March 25, 1896.

Loads.	North Side.					South Side.					Average difference of micrometer readings.	Average difference of abscissæ.	Average difference of ordinates.
	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.			
5,000	.5876 .5875	.5876	.....	.55	.36	.6204 .6205	.6205	.....	.43	.49	.....	.....	.....
10,000	.5769 .5769	.5769	.0107	.55	.36	.6143 .6145	.6144	.0061	.44	.48	.00840	.005	—.005
15,000	.5680 .5679	.5680	.0089	.57	.36	.6068 .6069	.6069	.0075	.45	.47	.00820	.015	—.005
20,000	.5581 .5581	.5581	.0099	.57	.37	.5990 .5991	.5991	.0078	.45	.47	.00885	.000	.005
25,000	.5485 .5485	.5485	.0096	.57	.37	.5912 .5913	.5913	.0078	.46	.47	.00870	.005	.000
30,000	.5395 .5396	.5396	.0089	.58	.36	.5830 .5830	.5830	.0083	.46	.47	.00860	.005	—.005
35,000	.5305 .5305	.5305	.0091	.58	.36	.5750 .5750	.5750	.0080	.47	.46	.00855	.005	—.005
40,000	.5211 .5210	.5211	.0094	.59	.36	.5667 .5667	.5667	.0083	.47	.46	.00885	.005	.000
45,000	.5120 .5118	.5119	.0092	.58	.35	.5582 .5583	.5583	.0084	.47	.46	.00880	—.005	—.005
50,000	.....	.....	.....	.60	.35	.....	.....	.....	.47	.45	.....	.010	—.005
55,000	.....	.....	.....	.61	.35	.....	.....	.....	.50	.45	.....	.020	.000
60,000	.....	.....	.....	.70	.35	.....	.....	.....	.56	.43	.....	.075	—.010

Nominal size of pipe	$3\frac{1}{2}''$	Maximum load	65,000 lbs.
Actual inside diameter	3.59″	Compression (5,000–35,000),	.05130″
Actual outside diameter	3.99″	Area of cross section	2.39 sq. in.
Length inside of flanges	$105\frac{3}{4}''$	Maximum load	27,200 lbs. per sq. in.
Diameter of flanges	$9\frac{1}{2}''$	Modulus of elasticity	24,600,000 lbs.
Gauge length	100.5″	$\frac{l}{\rho}$	78.5

TEST OF WROUGHT IRON PIPE COLUMN.

Date, March 16, 1896.

Loads.	North Side.					South Side.					Average difference of micrometer readings.	Average difference of abscissæ.	Average difference of ordinates.
	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.			
5,000	.5067	.5067	.....	.14	.27	.6468	.6468	.....	.39	.08	.....	.....	.....
	.5066					.6467							
10,000	.5031	.5031	.0036	.14	.26	.6386	.6387	.0081	.38	.06	.00585	—.005	—.015
	.5030					.6388							
15,000	.4970	.4971	.0060	.14	.26	.6316	.6316	.0071	.38	.06	.00655	.000	.000
	.4972					.6315							
20,000	.4910	.4911	.0060	.15	.26	.6251	.6252	.0064	.37	.06	.00620	.000	.000
	.4912					.6253							
25,000	.4857	.4858	.0053	.15	.25	.6179	.6179	.0073	.37	.04	.00630	.000	—.015
	.4858					.6178							
30,000	.4798	.4799	.0059	.15	.25	.6108	.6108	.0071	.37	.04	.00650	.000	.000
	.4799					.6108							
35,000	.4739	.4739	.0060	.15	.25	.6038	.6038	.0070	.36	.04	.00650	—.005	.000
	.4739					.6038							
40,000	.4678	.4678	.0061	.15	.25	.5971	.5971	.0067	.36	.04	.00640	.000	.000
	.4678					.5970							
40,000	.4662	.4661	.....	.13	.09	.6065	.6065	. ...	.35	.14	.....	.....	.....
	.4660					.6065							
45,000	.4602	.4602	.0059	.11	.08	.5998	.5998	.0067	.35	.14	.00630	—.010	—.005
	.4602					.5997							
50,000	.4536	.4535	.0067	.11	.08	.5948	.5948	.0050	.35	.13	.00585	.000	—.005
	.4534					.5949							
55,000	.4480	.4480	.0055	.11	.07	.5884	.5885	.0063	.35	.13	.00590	.000	—.005
	.4480					.5886							
60,000	.4416	.4416	.0064	.10	.07	.5817	.5817	.0068	.35	.13	.00660	—.005	.000
	.4416					.5816							
65,000	.4357	.4357	.0059	.10	.07	.5747	.5748	.0069	.35	.13	.00640	.000	.000
	.4357					.5749							
70,000	.4301	.4301	.0056	.10	.09	.5664	.5664	.0084	.33	.13	.00700	—.010	.010
	.4301					.5664							
75,000	.4247	.4248	.0053	.07	.09	.5542	.5542	.0122	.31	.13	.00875	—.025	.000
	.4248					.5542							

Nominal size of pipe	4″	Maximum load	80,000 lbs.
Actual inside diameter	4.07″	Compression (5,000–35,000),	.0379″
Actual outside diameter	4.53″	Area of cross section	3.11 sq. in.
Length inside of flanges	117⅞″	Maximum load	25,723 lbs. per sq. in.
Diameter of flanges	9½″	Modulus of elasticity	25,800,000 lbs.
Gauge length	100.5″	$\frac{l}{\rho}$	77.1

Held load for a moment, then deflected, breaking cap on east end.

TEST OF WROUGHT IRON PIPE COLUMN.

Date, March 20, 1896.

Loads.	North Side.					South Side.					Average difference of micrometer readings.	Average difference of abscissæ.	Average difference of ordinates.
	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.	Micrometer readings.	Mean.	Difference.	Abscissæ.	Ordinates.			
5,000	.6079 .6079	.6079	.....	.57	.58	.4374 .4374	.4374	.....	.52	.54	.....	....	....
10,000	.6010 .6009	.6010	.0069	.57	.60	.4296 .4294	.4295	.0079	.52	.57	.00740	.000	.025
15,000	.5927 .5928	.5928	.0082	.58	.61	.4221 .4220	.4221	.0074	.52	.58	.00780	.005	.010
20,000	.5849 .5848	.5849	.0079	.58	.62	.4154 .4154	.4154	.0067	.52	.59	.00730	.000	.010
25,000	.5783 .5782	.5783	.0066	.58	.63	.4090 .4091	.4091	.0063	.53	.59	.00645	.005	.005
30,000	.5698 .5699	.5699	.0084	.58	.63	.4025 .4025	.4025	.0066	.53	.59	.00750	.000	.000
35,000	.5618 .5619	.5619	.0080	.59	.63	.3958 .3956	.3957	.0068	.53	.59	.00740	.005	.000
Load allowed to go up until column was thrown out of line.													
35,000	.4460 .4460	.4460	.....	.97	.63	.4010 .4010	.4010	.....	.93	1.15	.....	.390	.280
40,000	.4372 .4372	.4372	.0088	.98	.64	.3946 .3946	.3946	.0064	.94	1.16	.00760	.010	.010
45,000	.4284 .4284	.4284	.0088	.99	.65	.3879 .3880	.3880	.0066	.95	1.17	.00770	.010	.010
50,000	.4199 .4198	.4199	.0085	1.00	.66	.3815 .3816	.3816	.0064	.96	1.18	.00745	.010	.010
60,000	.....	.....	.....	1.06	1.15	.....	.....	.....	.99	1.21	.....	.045	.260

Nominal size of pipe	4″	Maximum load	69,000 lbs.
Actual inside diameter	4.09″	Compression (5,000–35,000),	.04385″
Actual outside diameter	4.50″	Area of cross section	2.76 sq. in.
Length inside of flanges	117 $\frac{9}{16}$″	Maximum load	25,000 lbs. per sq. in.
Diameter of flanges	9$\frac{1}{4}$″	Modulus of elasticity	24,900,000 lbs.
Gauge length	100.5	$\frac{l}{\rho}$	77.3

Slight bend about two feet from end of pipe.

TRANSVERSE STRENGTH OF SPRUCE BEAMS.

No. of test.	Width and depth. (Inches.)	Distance between supports. (Feet.)	Manner of loading.	Breaking load.	Modulus of rupture. (Lbs. per sq. in.)	Modulus of elasticity. (Lbs. per sq. in.)	Maximum intensity of longitudinal shear. (Lbs. per sq. in.)	Manner of breaking.	Remarks.
505	6 x 12	15	Center.	14,800	4,670	....	153	Tension.	
507	4 x 11⅞	13	Center.	9,100	3,870	990,000	147	Tension.	
508	4 x 12	13	Center.	9,500	3,890	1,030,000	151	Tension.	
509	4 x 12	14	Center.	12,400	5,480	1,380,000	198	Tension.	
510	4⅛ x 11¾	12	Center.	10,130	4,060	1,190,000	161	Tension.	
511	3⅞ x 11¾	13	Center.	6,000	2,880	1,150,000	108	Tension.	
512	3⅞ x 12	12	Center.	10,170	4,100	1,020,000	172	Tension.	
513	4 x 12	14	Center.	9,600	4,270	974,000	155	Tension.	
514	4 x 12	12	Center.	10,400	3,930	976,000	165	Tension.	
515	4 x 12	12	Center.	8,780	3,320	883,000	139	Tension.	
516	4 x 12	13	Center.	12,260	5,030	1,110,000	195	Shear.	
521	4 x 12	12	Center.	11,650	4,400	1,090,000	185	Tension.	
525	4 x 12	14	Center.	10,640	4,690	1,110,000	169	Tension.	
526	1¾ x 11⅝	19	Center.	4,230	5,480	1,420,000	143	Tension.	Beam buckled badly.
527	3⅞ x 11¾	14	Center.	11,630	5,920	1,390,000	201	Tension.	
532	2 x 12	15	Center.	3,230	2,940	....	101	Tension and crushing.	

TRANSVERSE STRENGTH OF NORWAY PINE BEAMS.

No. of test.	Width and depth. (Inches.)	Distance between supports. (Feet.)	Manner of loading.	Breaking load.	Modulus of rupture. (Lbs. per sq. in.)	Modulus of elasticity. (Lbs. per sq. in.)	Maximum intensity of longitudinal shear. (Lbs. per sq. in.)	Manner of breaking.	Remarks.
528	2 x 11⅞	26	Center.	1,990	3,660	1,260,000	70	Tension.	
529	2 x 11⅞	26	Center.	3,690	6,340	2,020,000	125	Crushing.	Beam buckled badly each side of center.
530	2 x 12	13	Center.	8,030	6,570	.....	255	Shear, tension and crushing.	
531	2 x 12	15	Center.	8,530	8,055	.....	271	Tension.	
534	2 x 12	15	Center.	3,860	3,670	.....	124	Tension.	

Cement Tests.

The tests of cement in tension were made on briquettes of 1 square inch cross section in a machine of a special design, the description of which may be found in the *Brickbuilder*, Vol. 4, No. 12, 1895.

The tests in compression were made on 2″ cubes in an Olsen machine of 50,000 pounds capacity, fitted with special platforms for the purpose, the upper platform having a spherical bearing, which enables it to adjust itself to give as nearly as possible a uniformly distributed load upon the specimen. The results given are the total breaking loads upon the specimens.

The sand tests were made with ordinary building sand, which was sifted through a No. 20 sieve to take out the coarse particles. This does not give nearly as high results as can be obtained by using ground quartz, which is ordinarily used for this purpose. All specimens were set under water, the average temperature of the bath being about 70° F.

SAND TESTS. COMPRESSION.

Date of test.	Kind of cement.	Brand.	Parts of sand to one part cement.	Per cent. of water used in mixing.	Time of set days.	Breaking strength.
Nov. 18, 1895.	Portland.	Commercial American.	3	12	7	2,970
Nov. 18, 1895.	Portland.	Commercial American.	3	12	7	3,100
Dec. 16, 1895.	Portland.	Commercial American.	3	12	7	2,400
Dec. 16, 1895.	Portland.	Commercial American.	3	12	7	2,400
Dec. 16, 1895.	Portland.	Commercial American.	3	12	7	2,450
Dec. 6, 1895.	Portland.	Commercial American.	3	12	23	5,000
Dec. 6, 1895.	Portland.	Commercial American.	3	12	23	5,200
Mar. 18, 1896.	Portland.	Commercial American.	2	10	2	2,570
Mar. 18, 1896.	Portland.	Commercial American.	2	10	2	2,750
Mar. 18, 1896.	Portland.	Commercial American.	2	10	2	2,750
Mar. 18, 1896.	Portland.	Commercial American.	2	10	2	3,100
Mar. 27, 1896.	Portland.	Commercial American.	2	10	4	3,900
Mar. 27, 1896.	Portland.	Commercial American.	2	10	4	4,590
April 1, 1896.	Portland.	Commercial American.	2	10	5	4,760
April 2, 1896.	Portland.	Commercial American.	2	10	6	4,800
April 2, 1896.	Portland.	Commercial American.	2	10	6	5,150
Mar. 11, 1896.	Portland.	Commercial American.	2	10	7	5,450
Mar. 7, 1896.	Portland.	Commercial American.	2	10	7	5,780
Mar. 7, 1896.	Portland.	Commercial American.	2	10	7	5,950
Mar. 16, 1896.	Portland.	Commercial American.	2	10	11	9,390
Mar. 16, 1896.	Portland.	Commercial American.	2	10	11	9,800

SAND TESTS. TENSION.

Date of test.	Kind of cement.	Brand.	Parts of sand to one part cement.	Per cent. of water used in mixing.	Time of set days.	Breaking strength.
Nov. 18, 1895.	Portland.	Commercial American.	3	12	7	90
Dec. 4, 1895.	Portland.	Commercial American.	3	12	7	87
Dec. 4, 1895.	Portland.	Commercial American.	3	12	7	87
Dec. 4, 1895.	Portland.	Commercial American.	3	12	7	90
Dec. 16, 1895.	Portland.	Commercial American.	3	12	7	97
Dec. 16, 1895.	Portland.	Commercial American.	3	12	7	99
Dec. 9, 1895.	Portland.	Commercial American.	3	12	14	106
Dec. 9, 1895.	Portland.	Commercial American.	3	12	14	111
Dec. 6, 1895.	Portland.	Commercial American.	3	12	23	132
Dec. 6, 1895.	Portland.	Commercial American.	3	12	23	141
Mar. 11, 1896.	Portland.	Commercial American.	2	10	7	164
Mar. 11, 1896.	Portland.	Commercial American.	2	10	7	170
April 1, 1896.	Portland.	Commercial American.	2	10	7	160
April 1, 1896.	Portland.	Commercial American.	2	10	7	162
April 1, 1896.	Portland.	Commercial American.	2	10	7	170
April 1, 1896.	Portland.	Commercial American.	2	10	7	176
Mar. 16, 1896.	Portland.	Commercial American.	2	8	11	180
Mar. 16, 1896.	Portland.	Commercial American.	2	8	11	184
Mar. 16, 1896.	Portland.	Commercial American.	2	8	11	200

NEAT CEMENT. COMPRESSION.

Date of test.	Kind of cement.	Brand.	Per cent. of water used in mixing.	Time of set days.	Breaking strength.
Mar. 18, 1896.	Portland.	Commercial American.	25	2	6,750
Mar. 18, 1896.	Portland.	Commercial American.	25	2	6,680
Mar. 27, 1896.	Portland.	Commercial American.	25	4	8,700
Mar. 27, 1896.	Portland.	Commercial American.	25	4	8,770
Mar. 27, 1896.	Portland.	Commercial American.	25	4	8,800
Mar. 27, 1896.	Portland.	Commercial American.	25	4	9,380
Nov. 11, 1895.	Portland.	Commercial American.	26	4	8,450
Nov. 11, 1895.	Portland.	Commercial American.	26	4	8,510
Nov. 15, 1895.	Portland.	Commercial American.	27	7	10,000
Nov. 15, 1895.	Portland.	Commercial American.	27	7	10,200
Nov. 18, 1895.	Portland.	Commercial American.	27	7	10,530
Nov. 18, 1895.	Portland.	Commercial American.	27	7	10,020
Nov. 18, 1895.	Portland.	Commercial American.	27	7	10,150
Dec. 4, 1895.	Portland.	Commercial American.	27	7	10,230
Dec. 4, 1895.	Portland.	Commercial American.	27	7	10,320
Dec. 16, 1895.	Portland.	Commercial American.	27	7	10,000
Dec. 16, 1895.	Portland.	Commercial American.	27	7	10,450
Dec. 13, 1895.	Portland.	Commercial American.	27	7	11,280
Dec. 13, 1895.	Portland.	Commercial American.	27	7	10,960
Dec. 13, 1895.	Portland.	Commercial American.	27	7	10,690
April 3, 1896.	Portland.	Commercial American.	25	7	10,030
April 3, 1896.	Portland.	Commercial American.	25	7	10,350
April 3, 1896.	Portland.	Commercial American.	25	7	11,400
April 1, 1896.	Portland.	Commercial American.	25	7	10,790
April 1, 1896.	Portland.	Commercial American.	25	7	10,620
April 1, 1896.	Portland.	Commercial American.	25	7	10,830
April 1, 1896.	Portland.	Commercial American.	25	7	11,020
Mar. 31, 1896.	Portland.	Commercial American.	25	7	10,550
Mar. 13, 1896.	Portland.	Commercial American.	25	7	10,820
Mar. 13, 1896.	Portland.	Commercial American.	25	7	10,900
Mar. 13, 1896.	Portland.	Commercial American.	25	7	11,350
Mar. 11, 1896.	Portland.	Commercial American.	25	7	11,320
Mar. 11, 1896.	Portland.	Commercial American.	25	7	10,780
Mar. 11, 1896.	Portland.	Commercial American.	25	7	11,280
Nov. 20, 1895.	Portland.	Commercial American.	27	8	10,500
Nov. 20, 1895.	Portland.	Commercial American.	27	8	10,540
Nov. 20, 1895.	Portland.	Commercial American.	27	8	10,590
Dec. 13, 1895.	Portland.	Commercial American.	27	8	10,600
Dec. 13, 1895.	Portland.	Commercial American.	27	8	10,700
Nov. 15, 1895.	Portland.	Commercial American.	26	9	11,100
Nov. 15, 1895.	Portland.	Commercial American.	26	9	11,350
Nov. 15, 1895.	Portland.	Commercial American.	25	10	11,720
Nov. 15, 1895.	Portland.	Commercial American.	25	10	11,910
Dec. 7, 1895.	Portland.	Commercial American.	27	11	11,900
Dec. 7, 1895.	Portland.	Commercial American.	27	11	11,900
Dec. 6, 1895.	Portland.	Commercial American.	27	14	13,500
Dec. 6, 1895.	Portland.	Commercial American.	27	14	13,550
Dec. 6, 1895.	Portland.	Commercial American.	27	14	13,420
Dec. 6, 1895.	Portland.	Commercial American.	27	23	16,050
Dec. 6, 1895.	Portland.	Commercial American.	27	23	15,990
Dec. 6, 1895.	Portland.	Commercial American.	27	23	15,800
Nov. 1, 1895.	Portland.	B. S. & Co.	25	11	15,420
Nov. 1, 1895.	Portland.	B. S. & Co.	25	11	14,860
Mar. 22, 1895.	Portland.	Alsen.	28	2	7,580
Mar. 22, 1895.	Portland.	Alsen.	28	2	7,750
Mar. 22, 1895.	Portland.	Alsen.	28	2	8,130
Mar. 20, 1895.	Portland.	Alsen.	29	33	15,700
Nov. 18, 1895.	Portland.	Alsen.	29	276	37,750

NEAT CEMENT. TENSION.

Date of test.	Kind of cement.	Brand.	Per cent. of water used in mixing.	Time of set days.	Breaking strength.
Mar. 18, 1896.	Portland.	Commercial American.	25	2	270
Mar. 18, 1896.	Portland.	Commercial American.	25	2	270
Mar. 18, 1896.	Portland.	Commercial American.	25	2	288
Mar. 27, 1896.	Portland.	Commercial American.	25	4	344
Nov. 11, 1895.	Portland.	Commercial American.	26	4	340
Nov. 11, 1895.	Portland.	Commercial American.	26	4	345
Nov. 11, 1895.	Portland.	Commercial American.	26	4	369
Nov. 14, 1895.	Portland.	Commercial American.	27	6	370
Nov. 14, 1895.	Portland.	Commercial American.	27	6	371
Nov. 14, 1895.	Portland.	Commercial American.	27	6	372
Nov. 14, 1895.	Portland.	Commercial American.	27	6	390
April 2, 1896.	Portland.	Commercial American.	25	6	389
April 2, 1896.	Portland.	Commercial American.	25	6	389
Nov. 12, 1895.	Portland.	Commercial American.	25	7	415
Nov. 12, 1895.	Portland.	Commercial American.	25	7	440
Nov. 18, 1895.	Portland.	Commercial American.	27	7	412
Dec. 4, 1895.	Portland.	Commercial American.	27	7	414
Dec. 4, 1895.	Portland.	Commercial American.	27	7	470
Dec. 13, 1895.	Portland.	Commercial American.	27	7	400
Dec. 13, 1895.	Portland.	Commercial American.	27	7	405
Dec. 13, 1895.	Portland.	Commercial American.	27	7	410
Dec. 16, 1895.	Portland.	Commercial American.	27	7	412
Dec. 13, 1895.	Portland.	Commercial American.	27	7	420
April 3, 1896.	Portland.	Commercial American.	25	7	400
April 1, 1896.	Portland.	Commercial American.	25	7	434
Mar. 31, 1896.	Portland.	Commercial American.	25	7	438
April 1, 1896.	Portland.	Commercial American.	25	7	449
April 1, 1896.	Portland.	Commercial American.	25	7	451
April 1, 1896.	Portland.	Commercial American.	25	7	458
Mar. 11, 1896.	Portland.	Commercial American.	25	7	442
Mar. 11, 1896.	Portland.	Commercial American.	25	7	444
Dec. 13, 1895.	Portland.	Commercial American.	27	9	456
Mar. 13, 1896.	Portland.	Commercial American.	25	9	478
Mar. 13, 1896.	Portland.	Commercial American.	25	9	498
Mar. 16, 1896.	Portland.	Commercial American.	25	11	504
Dec. 6, 1895.	Portland.	Commercial American.	27	14	513
Dec. 6, 1895.	Portland.	Commercial American.	27	23	520
Dec. 6, 1895.	Portland.	Commercial American.	27	23	540
Oct. 28, 1895.	Portland.	B. S. & Co.	25	3	382
Oct. 28, 1895.	Portland.	B. S. & Co.	25	3	410
Oct. 28, 1895.	Portland.	B. S. & Co.	25	3	411
Oct. 30, 1895.	Portland.	B. S. & Co.	25	7	470
Oct. 31, 1895.	Portland.	B. S. & Co.	25	7	505
Nov. 15, 1895.	Portland.	B. S. & Co.	25	31	560
Nov. 15, 1895.	Portland.	B. S. & Co.	25	31	564
Nov. 15, 1895.	Portland.	B. S. & Co.	25	31	620
Nov. 18, 1895.	Portland.	B. S. & Co.	25	31	578
Nov. 18, 1895.	Portland.	B. S. & Co.	25	32	616
Nov. 18, 1895.	Portland.	B. S. & Co.	25	32	626
Nov. 18, 1895.	Portland.	B. S. & Co.	25	33	669
Nov. 18, 1895.	Portland.	B. S. & Co.	25	33	686
Dec. 20, 1895.	Portland.	B. S. & Co.	25	63	664
Dec. 20, 1895.	Portland.	B. S. & Co.	25	63	680
Dec. 20, 1895.	Portland.	B. S. & Co.	25	64	706
Dec. 20, 1895.	Portland.	B. S. & Co.	25	65	732
Dec. 20, 1895.	Portland.	B. S. & Co.	28	66	680
Oct. 23, 1895.	Portland.	Alsen.	25	2	418
Oct. 23, 1895.	Portland.	Alsen.	25	2	420
Oct. 23, 1895.	Portland.	Alsen.	25	2	430
Oct. 23, 1895.	Portland.	Alsen.	25	2	460
Oct. 19, 1894.	Portland.	Alsen.	30	6	590
Oct. 19, 1894.	Portland.	Alsen.	30	6	591
Oct. 19, 1894.	Portland.	Alsen.	30	6	600
Nov. 13, 1895.	Portland.	Alsen.	29	271	840
Nov. 13, 1895.	Portland.	Alsen.	29	271	860

Compression of Timber Across the Grain.

These tests were made on the 300,000-pound Emery testing machine.

The specimens were placed between the compression platforms of the machine and the load applied slowly. The platforms were adjusted so as to bear fairly on the two opposite faces of the specimen. It was found that the location of the heart with reference to the stick had considerable influence on the strength, and for this reason the sketches showing time rings were made.

Different sizes of specimens from the same wood were tried. In the larger sizes no maximum load was reached in many cases, the piece simply crushing together. This was to be expected with specimens of large section and of short length between the platforms.

BRIEF SUMMARY OF TESTS ON COMPRESSION OF TIMBER ACROSS THE GRAIN.

Kind of wood.	Approximate size of timber. (In.)	Number of tests.	Average of tests. (Lbs. per sq. in.)	Kind of wood.	Approximate size of timber. (In.)	Number of tests.	Average of tests. (Lbs. per sq. in.)	Kind of wood.	Approximate size of timber. (In.)	Number of tests.	Average of tests. (Lbs. per sq. in.)
Spruce.	2¾ x 10	60	396	Spruce.	4 x 6	5	511	Yellow Pine.	4 x 6	17	566
Spruce.	2 x 12	21	252	Spruce.	4 x 8	10	494	Oak.	4 x 12	60	898
Spruce.	3 x 12	23	350	Spruce.	6 x 8	5	424	Oak.	4 x 12	51	980
Spruce.	4 x 12	59	397	Yellow Pine.	4 x 12	60	535	Oak.	6 x 12	17	835
Spruce.	6 x 12	26	319	Yellow Pine.	6 x 12	16	402	Oak.	8 x 12	21	913
Spruce.	8 x 12	31	350	Yellow Pine.	8 x 12	18	471	Maple.	4 x 12	21	1808
Spruce.	10 x 12	5	664	Yellow Pine.	8 x 8	5	696	Hemlock.	4 x 12	20	330

The column marked "approximate size of timber" gives in the first figure the width of the stick bearing on the platform of the machine.

The second figure gives the distance between the compression platforms, or it corresponds to what would be the depth of the stick.

The length or the distance with the grain was in most cases 13 inches, this being about the limit of width of the platforms of the machine.

Results of Tests on the Crushing Strength of Spruce, Across the Grain.

2½"x10"		2"x12"			3"x12"			4"x12"			6"x12"			8"x12"			10"x12"			12"x12"			4"x14"			4"x16"			4"x18"			5"x18"			8"x16"			8"x18"		
Section	Creep's	Section	Creep's	Max. lbs per sq. in.	Section	Creep's	Max. lbs per sq. in.	Section	Creep's	Max. lbs per sq. in.	Section	Creep's	Max. lbs per sq. in.	Section	Creep's	Max. lbs per sq. in.	Section	Creep's	Max. lbs per sq. in.	Section	Creep's	Max. lbs per sq. in.	Section	Creep's	Max. lbs per sq. in.	Section	Creep's	Max. lbs per sq. in.	Section	Creep's	Max. lbs per sq. in.	Section	Creep's	Max. lbs per sq. in.	Section	Creep's	Max. lbs per sq. in.	Section	Creep's	Max. lbs per sq. in.
	375		262			500		397			471			341			873																				
	506		231			323		343			307			347			592																				
	411		193			284		357			386			343			792																				
	345		281			308		401			282			258			373																				
	281		269			585		326			283			370			689																				
	408		222			351		324			317			654																								
	269		258			305		411			307			515																								
	315		166			346		282			244			384																								
	262		272			339		287			281			300																								
	316		226			340		427			287			372																								
	300		297			299		407			300			298																								
	400		296			301		207			311			379																								
	320		358			299		296			289			353																								
	362		287			340		300			371			266																								
	235		237			436		417			359			316																								
	294		269			317		354			279			406																								
	214		213			334		329			327			354																								
	248		298			315		288			353			333																								
	360		203			311		224			353			352																								
	320		175			471		337			309			394																								
	325		281			284		325			304			351																								
	381					332		287			295			358																								
	461					337		345			317			304																								
	442							327			260			360																								
	399							246			342			322																								
	364							331			423			272																								
	456							329						353																								
	316							278						255																								
	436							248						298																								
	416							397						340																								
	372							361						284																								
	417							373																														
	428							365																														
	448							283																														
	538							344																														
	383							532																														
	313							302																														
	414							845																														
	473							552																														
	355							393																														
	377							853																														
	302							591																														
	383							539																														
	831							543																														
	490							396																														
	536							366																														
	380							473																														
	440							375																														
	464							813																														
	440							304																														
	697							349																														
	400							358																														
	695							591																														
	604							590																														
	465							443																														
	461							421																														
	408							440																														
	289							469																														
	500							598																														
	431																																				

Results of Tests of the Crushing Strength of Timber, Across the Grain.

Yellow Pine 4"x12"			Yellow Pine 6"x12"			Yellow Pine 8"x12"			Yellow Pine 4"x6"			Yellow Pine 8"x8"			Oak 4"x12"			Oak 4"x12"			Oak 6"x12"			Oak 8"x12"			Maple 4"x12"			Hemlock 4"x12"		
Section	Crushg's	Mean Res per sq ft	Section	Crushg's	Mean Res per sq ft	Section	Crushg's	Mean Res per sq ft	Section	Crushg's	Mean Res per sq ft	Section	Crushg's	Mean Res per sq ft	Section	Crushg's	Mean Res per sq ft	Section	Crushg's	Mean Res per sq ft	Section	Crushg's	Mean Res per sq ft	Section	Crushg's	Mean Res per sq ft	Section	Crushg's	Mean Res per sq ft	Section	Crushg's	Mean Res per sq ft
	422			490			500			552			810			715			738			715			547			1288			311
	552			337			422			576			697			589			771			892			742			1142			323
	790			314			528			500			678			971			1032			904			1069			1099			279
	470			492			472			457			700			657			679			1048			791			3957			294
	560			501			497			592			597			703			763			798			870			1095			514
	414			319			462			644						636			1096			846			950			1099			369
	424			417			427			739						798			1046			895			1806			4343			358
	472			423			581			583						1105			826			845			1198			3960			319
	832			348			465			544						1030			893			800			988			1175			431
	418			342			505			522						813			1146			777			791			4445			471
	473			448			492			543						870			764			873			809			1400			266
	481			446			433			620						963			1110			580			911			1863			283
	438			478			458			518						719			1588			940			1003			1157			289
	523			340			429			537						742			1650			784			935			1018			294
	476			319			402			485						678			858			848			788			1013			260
	473			411			424			639						758			1160			823			976			662			304
	532						519			586						711			1750			875			1018			1787			296
	418						468									845			1110						1125			2114			301
	429															975			710						866			2164			321
	651															703			802						780			987			340
	612															933			1278						1065			1167			
	514															981			893												
	559															653			1388												
	501															808			1360												
	447															785			1010												
	481															901			1210												
	436															814			1025												
	481															879			1270												
	505															793			1090												
	488															1010			1077												
	475															702			1038												
	434															802			1112												
	469															856			1090												
	551															798			854												
	500															837			905												
	540															1170			769												
	430															731			1108												
	593															758			760												
	404															671			1830												
	605															870			686												
	509															2132			1211												
	505															1002			1204												
	560															1115			721												
	528															2404			738												
	680															813			974												
	698															736			616												
	687															885			715												
	813															1242			860												
	580															773			677												
	552															712			813												
	729															926			673												
	711															1231															
	582															824															
	537															1334															
	505															780															
	745															716															
	519															893															
	514															944															
	514															1171															
	489															748															

Tension Tests

TENSION TESTS.

Date.	Specimen.	Dimensions of cross section. (Inches.)	Area of cross section. (Sq. ins.)	Gauged length. (Ins.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Elastic elongation for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)
1895.							
Oct. 21	Refined iron.	.76 diameter.	.454	10.00	.....	.....	.....
Oct. 23	Refined iron.	.77 diameter.	.466	10.00	500 to 6,500	.0048	26,800,000
Oct. 25	Refined iron.	.75 diameter.	.442	10.00	500 to 6,500	.0050	27,200,000
Oct. 26	Refined iron.	.75 diameter.	.442	10.00	500 to 6,500	.0052	26,100,000
Oct. 28	Refined iron.	.76 diameter.	.454	10.00	500 to 6,500	.0056	26,000,000
Oct. 31	Refined iron.	4.00 × 1.01	4.04	14.00	.....	.....	.....
Nov. 4	Refined iron.	.76 diameter.	.454	11.00	.....	.....	.....
Nov. 4	Refined iron.	.76 diameter.	.454	11.00	500 to 6,500	.0047	31,000,000
Nov. 4	Wrought iron.	4.00 × 1.00	4.00	25.00	.....	.....	.....
Nov. 6	Refined iron.	.75 diameter.	.442	11.00	500 to 6,500	.0052	28,700,000
Nov. 7	Refined iron.	.76 diameter.	.454	11.00	.....	.....	.....
Nov. 12	Bessemer steel.	.76 diameter.	.454	11.00	500 to 6,500	.0046	31,600,000
Nov. 13	Bessemer steel.	.76 diameter.	.454	11.00	.....	.....	.....
Nov. 14	Wrought iron, Burden's Best.	.76 diameter.	.454	11.00	500 to 6,500	.0046	31,600,000
Nov. 15	Wrought iron, Burden's Best.	.75 diameter.	.442	11.00	500 to 6,500	.0052	28,700,000
Nov. 20	Wrought iron, Burden's Best.	.75 diameter.	.442	11.00	500 to 6,500	.0051	29,300,000
Nov. 22	Wrought iron, Burden's Best.	.77 diameter.	.466	11.00	500 to 6,500	.0051	27,800,000
Nov. 25	Wrought iron, Burden's Best.	.76 diameter.	.454	11.00	500 to 6,500	.0049	29,700,000
Nov. 27	Wrought iron, Burden's Best.	.77 diameter.	.466	11.00	500 to 6,500	.0046	28,200,000
1896.							
Jan. 4	Steel.	$2.00 \times \frac{1}{2}(.0875 + .0890)$	.1765	10.00	500 to 12,500	.0232	29,370,000
Jan. 4	Steel.	$2.00 \times \frac{1}{2}(.0960 + .1005)$	.1965	10.00	1,500 to 16,500	.0255	29,940,000
Jan. 15	Steel.	$2.01 \times \frac{1}{2}(.0902 + .0912)$	.1823	10.00	500 to 10,500	.0190	28,870,000
Jan. 15	Steel.	$2.01 \times .1015$	.2040	10.00	1,500 to 17,500	.0294	26,700,000
Jan. 15	Steel.	$2.00 \times \frac{1}{2}(.0909 + .0908)$	.1817	10.00	1,500 to 13,500	.0223	29,620,000
Jan. 15	Steel.	$2.00 \times .0911$	.1822	10.00	500 to 16,500	.0280	29,610,000
Mar. 17	Composition.	.755 diameter.	.448	10.00	500 to 3,500	.0050	13,400,000
Mar. 18	Brass rod.	.756 diameter.	.449	10.00	5,500 to 9,500	.0062	14,300,000
Mar. 23	Brass rod.	.754 diameter.	.446	10.00	500 to 6,500	.0088	15,300,000
Mar. 24	Brass.	.754 diameter.	.446	10.00	500 to 1,500	.0020	11,200,000
Mar. 27	Composition.	1.014 diameter.	.808	10.00	500 to 3,500	.0027	13,700,000
Mar. 30	Steel tape.	.2215 × .0082	.00184	.....	.....	.....	.....
Mar. 31	Steel tape.	.2735 × .0113	.00309	.....	.....	.....	.....
April 2	Aluminum alloy.	1.46 × .53	.774	8.00	500 to 3,500	.0036	8,610,000
May 1	Bronze alloy.	1.54 × .52	.881	6.00	1,000 to 5,000	.0028	10,700,000

TENSION TESTS.—*Continued.*

Elastic limit. (Lbs.)	Elastic limit. (Lbs. per sq. in.)	Maximum load. (Lbs.)	Maximum load. (Lbs. per sq. in.)	Area of fractured section. (Sq. ins.)	Reduction in area. (Per cent.)	Ultimate extension in gauged length. (Ins.)	Ultimate extension in gauged length. (Per ct.)	Remarks.
11,000	24,200	23,760	52,500	.353	22.3	2.25	22.5	
16,000	34,400	36,000	77,300	.342	26.5	....	....	
15,000	34,000	23,450	53,100	.332	24.9	....	....	
14,000	31,700	23,350	52,900	.322	27.2	....	....	
13,000	28,700	23,400	51,600	.353	22.3	....	....	
.....	.....	164,300	40,700	3.46	14.4	2.25	16.0	
13,000	28,700	24,100	53,100	.342	24.6	2.19	19.9	
15,000	33,100	23,680	52,200	.332	26.9	2.12	19.3	
.....	.....	156,400	39,100	3.47	13.3	2.20	8.8	
14,000	31,700	22,150	50,100	.342	22.6	....	....	Specimen fractured outside measured section.
12,000	26,500	22,400	49,400	.332	26.9	1.47	13.4	
12,000	26,500	22,150	48,800	.132	70.9	3.62	32.9	
13,000	28,700	22,250	49,000	.145	68.0	3.50	31.8	
12,000	26,500	22,450	49,500	.204	55.0	3.50	31.8	
12,000	27,200	21,400	48,400	.237	46.2	3.00	27.3	
12,000	27,200	21,050	47,600	.221	50.1	3.00	27.3	
11,000	23,600	22,000	47,200	.204	56.1	3.31	30.1	
11,000	24,200	21,200	46,700	.264	41.8	3.06	27.8	
11,000	23,600	21,280	45,600	.212	54.5	3.44	31.3	
16,500	93,500	27,480	155,700	.1435	18.7	.87	8.7	
18,000	91,600	27,720	141,100	.1522	22.5	1.12	11.2	
15,500	85,000	22,490	123,400	.1482	18.7	.78	7.8	Covered with dark oxide and curved considerably.
20,500	100,500	30,550	149,700	.1950	4.4	.06	6.0	Covered with dark oxide and curved considerably.
18,500	101,800	24,500	134,800	.1490	18.0	.78	7.8	Covered with dark oxide and curved considerably.
16,000	88,000	25,380	139,300	.1166	36.0	.62	6.2	
.....	.....	13,200	29,400	.351	21.8	1.28	12.8	Composition: 85% copper, 7% spelter, 8% zinc.
.....	.....	31,650	70,500	.235	47.6	....	....	Fractured outside measured section.
.....	.....	31,333	70,200	.227	49.1	....	....	Specimen fractured in the grips.
.....	.....	10,260	23,009	.358	19.9	....	....	Specimen fractured outside measured section.
.....	.....	23,330	28,900	.601	25.6	....	....	Specimen fractured outside measured section.
.....	.....	450	245,000	....	....	....	....	
.....	.....	782	253,000	....	....	....	....	
.....	.....	4,720	6,100	.759	1.9	None.	....	
.....	.....	11,150	13,900	....	...	.....	....	Specimen fractured outside measured section.

TENSION TEST.

Specimen, Steel. Date, January 4, 1896.

Loads.	Micrometer Readings.				Mean.	Differences.		Remarks.
Actual.	1	2	1	2		Actual.	Per 500 lbs.	
500	.5035	.5034	.4393	.4392	.4714	.....	.....	
5,000	.5165	.5165	.4428	.4428	.4797	.0083	.0009	Broke outside measured section.
5,000	.5304	.5304	.4566	.4567	.4935	.....	.....	
10,000	.5407	.5407	.4659	.4659	.5033	.0098	.0010	
12,500	.5458	.5458	.4709	.4709	.5084	.0051	.0010	
13,000	.5469	.5469	.4721	.4719	.5095	.0011	.0011	
13,500	.5479	.5479	.4729	.4727	.5104	.0009	.0009	
14,000	.5489	.5489	.4736	.4737	.5113	.0009	.0009	
14,500	.5497	.5497	.4738	.4748	.5123	.0010	.0010	
15,000	.5508	.5509	.4758	.4757	.5133	.0010	.0010	
15,500	.5520	.5519	.4768	.4767	.5144	.0011	.0011	
16,000	.5530	.5530	.4779	.4779	.5154	.0010	.0010	
16,500	.5539	.5539	.4787	.4787	.5163	.0009	.0009	
17,000	.5552	.5551	.4800	.4799	.5176	.0013	.0013	
17,500	.5565	.5565	.4812	.4813	.5189	.0013	.0013	
18,000	.5581	.5582	.4830	.4830	.5206	.0017	.0017	
18,500	.5606	.....	.4853	. ....	.5230	.0024	.0024	

Length between clamps . . .	10″	Area of original section; sq. ins.	.1765
Dimensions of cross section . .	$2 \times \frac{1}{2}(.0875 + .089)$″	Elastic limit; lbs. per sq. in.	93,500
Elastic limit	16,500 lbs.	Maximum load; lbs. per sq. in. orig. sect.,	155,700
Maximum load	27,480 lbs.	Area of fractured section; sq. in.	.1435
Dimensions of fractured section .	1.84″ × .078″	Reduction of area of cross section; per cent.,	18.7
Ultimate extension	.875″	Ultimate extension; per cent.	8.75
Elastic elongation for 12,000 lbs. load equals	.0232″	Modulus of elasticity	29,370,000

TENSION TEST.

Specimen, Steel. Date, January 4, 1896.

Loads.	Micrometer Readings.				Mean.	Differences.	
Actual.	1	2	1	2		Actual.	Per 500 lbs.
1,500	.4361	.4361	.5105	.5105	.4733	.....	.....
1,600	.4620	.4619	.5340	.5341	.4980	.0247	.0009
16,500	.4627	.4628	.5350	.5348	.4988	.0008	.0008
17,000	.4636	.4638	.5358	.5358	.4998	.0010	.0010
17,500	.4646	.4646	.5372	.5371	.5009	.0011	.0011
18,000	.4656	.4654	.5381	.5383	.5019	.0010	.0010
18,500	.4672	.....	.5413	.....	.5043	.0024	.0024

Length between clamps . . .	10″	Area of original section; sq. ins.	.1965
Dimensions of cross section . .	$2 \times \frac{1}{2}(.096 + .1005)$″	Elastic limit; lbs. per sq. in.	91,600
Elastic limit	1,800 lbs.	Maximum load; lbs. per sq. in. orig. sect. .	141,100
Maximum load	27,720 lbs.	Area of fractured section; sq. in.	.1522
Dimensions of fractured section .	1.79″ × .085″	Reduction of area of cross section; per cent.,	22.5
Ultimate extension	1.125″	Ultimate extension; per cent.	11.25
Elastic elongation for 15,000 lbs. load equals	.0255″	Modulus of elasticity	29,940,000

TENSION TEST.

Specimen, Steel. Date, January 15, 1896.

Loads. Actual.	Micrometer Readings. 1	2	1	2	Mean.	Differences. Actual.	Per 500 lbs.	Remarks.
500	.4859	.4858	.5063	.5063	.4960	.....	.....	Covered with dark oxide and curved considerably.
6,500	.4993	.4993	.5062	.5162	.5078	.0117	.0010	
10,500	.5044	.5044	.5257	.5260	.5151	.0073	.0009	
14,500	.5103	.5104	.5350	.5350	.5227	.0076	.0009	
15,500	.5109	.5108	.5384	.5382	.5246	.0019	.0010	
16,000	.5117	.5117	.5407	.5407	.5262	.0016	.0016	
16,500	.5120	.5119	.5431	.5433	.5276	.0014	.0014	Broke outside measured section.
17,000	.5124	.5126	.5453	.5452	.5288	.0012	.0012	
17,500	.5170	.....	.5515	.....	.5343	.0055	.0055	

Length between clamps . .	10″	Area of original section; sq. ins.	.1823
Dimensions of cross section .	2.01 × ½(.0902 + .0912)″	Elastic limit; lbs. per sq. in.	85,000
Elastic limit	15,500 lbs.	Maximum load; lbs. per sq. in. orig. sect. .	123,400
Maximum load	22,490 lbs.	Area of fractured section; sq. in. . . .	.1482
Dimensions of fractured sect.,	1.83″ × .081″	Reduction of area of cross section; per cent.,	18.7
Ultimate extension	.78″	Ultimate extension; per cent.	7.8
Elastic elongation for 10,000 lbs. load equals	0.0190″	Modulus of elasticity	28,870,000

TENSION TEST.

Specimen, Steel. Date, January 15, 1896.

Loads. Actual.	Micrometer Readings. 1	2	1	2	Mean.	Differences. Actual.	Per 500 lbs.	Remarks.
1,500	.7266	.7266	.6941	.6941	.7104	.....	.....	
15,500	.7398	.7398	.7315	.7316	.7357	.0253	.0009	Covered with dark oxide and curved considerably.
17,500	.7436	.7437	.7360	.7360	.7398	.0041	.0010	
19,000	.7468	.7468	.7388	.7388	.7428	.0030	.0010	
19,500	.7475	.7476	.7440	.7399	.7438	.0010	.0010	
20,000	.7480	.7480	.7415	.7416	.7448	.0010	.0010	
20,500	.7491	.7489	.7427	.7428	.7459	.0011	.0011	Broke outside measured section.
21,000	.7502	.7502	.7443	.7442	.7472	.0013	.0013	
21,500	.7513	.7512	.7454	.7456	.7484	.0012	.0012	
22,000	.7521	.7521	.7468	.7468	.7495	.0011	.0011	
22,500	.7533	.7534	.7480	.7480	.7507	.0012	.0012	
23,500	.7559	.7561	.7508	.7509	.7534	.0027	.0014	
24,000	.7574	.7573	.7523	.7522	.7548	.0014	.0014	
24,500	.7589	.7587	.7540	.7540	.7564	.0016	.0016	
25,000	.7602	.....	.7558	.....	.7580	.0016	.0016	
25,500	.7618	.....	.7583	.....	.7601	.0021	.0021	

Length between clamps	10″	Area of original section; sq. ins.	.20402
Dimensions of cross section	2.01″ × .1015″	Elastic limit; lbs. per sq. in.	100,500
Elastic limit	20,500 lbs.	Maximum load; lbs. per sq. in. orig. sect. .	149,700
Maximum load	30,550 lbs.	Area of fractured section; sq. in.	.19502
Dimensions of fractured section . .	1.96″ × .0995″	Reduction of area of cross section; per cent.,	4.4
Ultimate extension	.06″	Ultimate extension; per cent.	.6
Elastic elongation for 16,000 lbs. load equals	.0294″	Modulus of elasticity	26,700,000

TENSION TEST.

Specimen, Steel. Date, January 15, 1896.

Loads. Actual.	Micrometer Readings. 1	2	1	2	Mean.	Differences. Actual.	Per 500 lbs.	Remarks.
1,500	.4561	.4559	.5223	.5224	.4892	.....	.....	
13,500	.4836	.4834	.5394	.5394	.5115	.0223	.0009	Covered with dark-colored oxide and curved considerably.
14,500	.4853	.4852	.5413	.5414	.5133	.0018	.0009	
15,000	.4862	.4862	.5422	.5422	.5142	.0009	.0009	
15,500	.4872	.4870	.5432	.5430	.5151	.0009	.0009	
16,000	.4882	.4881	.5442	.5440	.5161	.0010	.0010	
16,500	.4891	.4891	.5452	.5454	.5172	.0011	.0011	
17,500	.4916	.4916	.5469	.5469	.5192	.0020	.0010	
18,000	.4926	.4927	.5478	.5478	.5203	.0011	.0011	
18,500	.4942	.4940	.5483	.5484	.5212	.0009	.0009	
19,000	.4960	.4988	.5496	.5497	.5228	.0016	.0016	
19,500	.4988	.....	.5533	.....	.5261	.0033	.0033	

Length between clamps	10″	Area of original section; sq. ins.	.1817
Dimensions of cross section	$2 \times \frac{1}{2}(.0909 + .0908)$″	Elastic limit; lbs. per sq. in.	101,800
Elastic limit	18,500 lbs.	Maximum load; lbs. per sq. in. orig. sect.	134,800
Maximum load	24,500 lbs.	Area of fractured section; sq. in.	.1490
Dimensions of fractured section,	1.84″ × .081″	Reduction of area of cross section; per cent.,	18.0
Ultimate extension	.78″	Ultimate extension; per cent.	7.8
Elastic elongation for 12,000 lbs. load equals	.0223″	Modulus of elasticity	29,620,000

TENSION TEST.

Specimen, Steel. Date, January 15, 1896.

Loads. Actual.	Micrometer Readings. 1	2	1	2	Mean.	Differences. Actual.	Per 500 lbs.	Remarks.
500	.4469	.4471	.4924	.4926	.4698	.....	.....	
15,500	.4815	.4813	.5141	.5141	.4978	.0280	.0009	Broke outside measured section.
16,000	.4825	.4823	.5149	.5150	.4987	.0009	.0009	
16,500	.4836	.4837	.5166	.5167	.5002	.0015	.0015	

Length between clamps	10″	Area of original section; sq. ins.	.1822
Dimensions of cross section	2″ × .0911″	Elastic limit; lbs. per sq. in.	88,000
Elastic limit	16,000 lbs.	Maximum load; lbs. per sq. in. orig. sect.	139,300
Maximum load	35,380 lbs.	Area of fractured section; sq. in.	.1166
Dimensions of fractured section	1.85″ × .063″	Reduction of area of cross section; per cent.,	36.0
Ultimate extension	.625″	Ultimate extension; per cent.	6.25
Elastic elongation for 15,000 lbs. load equals	.0280″	Modulus of elasticity	29,610,000

TENSION TEST.

Specimen, Composition. Date, March 17, 1896.

Loads.	Micrometer Readings.				Mean.	Differences.	Remarks.
Actual.	1	2	1	2		Actual.	
500	.1158	.1157	.1211	.1209	.1184	.....	
3,500	.1223	.1223	.1246	.1245	.1234	.0050	85% copper.
4,500	.1250	.1252	.1261	.1262	.1256	.0022	7% spelter.
5,500	.1302	.1301	.1296	.1295	.1298	.0042	8% zinc.
6,500	.1467	.1465	.1447	.1445	.1456	.0158	

Length between clamps	10″	Area of original section; sq. ins.	.448
Dimension of cross section	.7555″ dia.	Maximum load; lbs. per sq. in. orig. sect.	29,400
Maximum load	13,200 lbs.	Area of fractured section; sq. in.	.351
Dimension of fractured section	.6681″ dia.	Reduction of area of cross section; per cent.,	21.8
Ultimate extension	1.28″	Ultimate extension; per cent.	12.8
Elastic elongation for 3,000 lbs. load equals,	.005″	Modulus of elasticity	13,400,000

TENSION TEST.

Specimen, Brass Rod. Date, March 18, 1896.

Loads.	Micrometer Readings.				Mean.	Differences.		Remarks.
Actual.	1	2	1	2		Actual.	Per 1,000 lbs.	
500	.1170	.1172	.2781	.2779	.1976	.....	.....	
1,500	.1181	.1181	.2922	.2924	.2052	.0076	.0076	Fractured in holder.
2,500	.1189	.1189	.2940	.2940	.2065	.0013	.0013	
3,500	.1202	.1203	.2954	.2953	.2078	.0013	.0013	
4,500	.1215	.1216	.2972	.2972	.2094	.0016	.0016	
5,500	.1230	.1231	.2990	.2990	.2110	.0016	.0016	
6,500	.1236	.1238	.3000	.3000	.2119	.0009	.0016	
7,000	.1250	.1251	.3007	.3009	.2129	.0010	.....	
7,500	.1256	.1256	.3019	.3019	.2138	.0009	.0019	
8,000	.1263	.1263	.3029	.3028	.2146	.0008	.....	
8,500	.1271	.1271	.3036	.3036	.2154	.0008	.0016	
9,000	.1281	.1280	.3043	.3045	.2163	.0009	.....	
9,500	.1288	.1288	.3055	.3054	.2172	.0009	.0018	
10,000	.1294	.1294	.3058	.3059	.2176	.0004	.....	
10,500	.1299	.1300	.3069	.3069	.2185	.0009	.0013	
11,000	.1307	.....	.3078	.....	.2192	.0007	.....	
11,500	.1315	.....	.3088	.....	.2202	.0010	.0017	
12,000	.1327	.....	.3096	.....	.2212	.0010	.....	
12,500	.1332	.....	.3101	.....	.2217	.0005	.0015	
13,000	.1339	.....	.3111	.....	.2225	.0008	.....	
13,500	.1348	.....	.3117	.....	.2233	.0008	.0016	
14,000	.1356	.....	.3125	.....	.2241	.0008	.....	
14,500	.1361	.....	.3137	.....	.2246	.0005	.0013	
15,000	.1370	.....	.3140	.....	.2255	.0009	.0018	
16,000	.1384	.....	.3156	.....	.2270	.0015	.0015	
17,000	.1408	.....	.3184	.....	.2296	.0026	.0026	
18,000	.1422	.....	.3203	.....	.2313	.0017	.0017	
19,000	.1442	.....	.3218	.....	.2330	.0017	.0017	
20,000	.1462	.....	.3238	.....	.2350	.0020	.0020	
21,000	.1488	.....	.3257	.....	.2372	.0022	.0023	
22,000	.1509	.....	.3281	.....	.2395	.0023	.0020	
24,000	.1551	.....	.3318	.....	.2435	.0040	.0035	
26,000	.1613	.....	.3396	.....	.2505	.0070	.0027	
28,000	.1683	.....	.3434	.....	.2559	.0054	.0072	
30,000	.1823	.....	.3583	.....	.2703	.0144	.....	

Length between clamps	10″	Area of original section; sq. ins.	.449
Dimension of cross section	.756″ dia.	Maximum load; lbs. per sq. in. orig. sect.	70,500
Maximum load	31,650 lbs.	Area of fractured section; sq. in.	.235
Dimension of fractured section	.5475″ dia.	Reduction of area of cross section; per cent.,	47.6
Elastic elongation from 5,500 to 9,500 lbs. load equals	.0062″	Modulus of elasticity	14,300,000

TENSION TEST.

Specimen, Brass Rod. Date, March 23, 1896.

Loads. Actual.	Micrometer Readings. 1	2	1	2	Mean.	Differences. Actual.	Remarks.
500	.1069	.1067	.3612	.3612	.2340	.....	
3,500	.1112	.1111	.3655	.3656	.2383	.0043	Specimen fractured in holder.
6,500	.1160	.1159	.3696	.3698	.2428	.0045	
500	.1082	.1081	.3600	.3599	.2340	.....	
10,000	.1222	.1223	.3746	.3746	.2484	.....	At 30,000 in. lbs. load the scale beam dropped.
12,000	.1250	.1251	.3781	.3781	.2516	.0032	
14,000	.1286	.1284	.3816	.3814	.2550	.0034	
16,000	.1322	.1321	.3850	.3849	.2585	.0035	
18,000	.1356	.1358	.3895	.3893	.2625	.0040	
20,000	.1401	.1402	.3933	.3932	.2667	.0042	
22,000	.1447	.1445	.3981	.3982	.2714	.0047	
24,000	.1492	.1493	.4025	.4025	.2759	.0045	
26,000	.1553	.1551	.4152	.4152	.2814	.0055	
28,000	.1628	.1627	.4152	.4152	.2890	.0076	

Length between clamps . . . . . 10″
Dimension of cross section . . . . . 0.754″ dia.
Maximum load . . . . . 31,333 lbs.
Dimension of fractured section . . . . .538″ dia.
Elastic elongation for 6,000 lbs. load equals, .0088″
Area of original section; sq. ins. 446
Maximum load; lbs. per sq. in. orig. sect., 70,200
Area of fractured section; sq. in. 227
Reduction of area of cross section; per cent., 49.1
Modulus of elasticity 15,300,000

TENSION TEST.

Specimen, Brass. Date, March 24, 1896.

Loads. Actual.	Micrometer Readings. 1	2	1	2	Mean.	Differences. Actual.	Remarks.
500	.3512	.3511	.1021	.1023	.2267	.....	65 % copper.
1,000	.3536	.3536	.1020	.1018	.2278	.0011	35 % spelter.
1,500	.3543	.3541	.1030	.1032	.2287	.0009	
2,000	.3552	.3552	.1041	.1043	.2297	.0010	Fractured outside measured section.
2,500	.3572	.3571	.1056	.1054	.2316	.0019	
3,000	.3608	.3609	.1095	.1094	.2352	.0036	
3,500	.3695	.3700	.1191	.1188	.2445	.0093	

Length between clamps . . . . . 10″
Dimension of cross section . . . . . .754″ dia.
Maximum load . . . . . 10,260 lbs.
Dimension of fractured section . . . . . .675″ dia.
Elastic elongation for 1,000 lbs. load equals, .0020″
Area of original section; sq. ins. 446
Maximum load; lbs. per sq. in. orig. sect. . 23,000
Area of fractured section; sq. in. 358
Reduction of area of cross section; per cent., 19.9
Modulus of elasticity 11,200,000

TENSION TEST.

Specimen, Composition. Date, March 27, 1896.

Loads. Actual.	Micrometer Readings. 1	2	1	2	Mean.	Differences. Actual.	Remarks.
500	.1510	.1512	.3785	.3786	.2648	.....	85% copper.
1,500	.1520	.1520	.3795	.3793	.2657	.0009	7% spelter.
2,500	.1523	.1525	.3800	.3802	.2662	.0005	8% tin.
3,500	.1540	.1540	.3812	.3810	.2675	.0013	
4,500	.1549	.1549	.3819	.3819	.2684	.0009	Fractured outside measured section.
5,500	.1568	.1570	.3836	.3838	.2703	.0019	
6,500	.1580	.1580	.3848	.3846	.2713	.0010	
7,500	.1590	.1588	.3871	.3870	.2730	.0017	
8,500	.1614	.1612	.3884	.3883	.2748	.0018	
9,500	.1638	.1636	.3890	.3891	.2764	.0016	

Length between clamps . . . . . 10″
Dimension of cross section . . . . . 1.0144″ dia.
Maximum load . . . . . 23,330 lbs.
Dimension of fractured section . . . . .8750″ dia.
Elastic elongation for 3,000 lbs. load equals, .0027″

Area of original section; sq. ins. 808
Maximum load; lbs. per sq. in. orig. sect., 28,900
Area of fractured section; sq. in. 601
Reduction of area of cross section; per cent., 25.6
Modulus of elasticity 13,700,000

TENSION TEST.

Specimen, Aluminum Alloy. Date, April 2, 1896.

Loads. Actual.	Per sq. in.	Micrometer Readings. 1	2	1	2	Mean.
500	.1743	.1741	.1540	.1538	.1640	.....
1,000	.1732	.1732	.1554	.1555	.1643	.0003
1,500	.1737	.1735	.1561	.1560	.1648	.0005
2,500	.1731	.1730	.1591	.1590	.1660	.0012
3,500	.1742	.1742	.1607	.1607	.1674	.0014
4,500	.1753	.1753	.1629	.1628	.1691	.0017

Length between clamps . . . . . 8″
Dimensions of cross section . . . . . .53″ x 1.46″
Maximum load . . . . . 4,720 lbs.
Dimensions of fractured section . . . .52″ x 1.46″
Ultimate extension . . No apparent extension in 8″

Elastic elongation for 3,000 lbs. load equals, .0036″
Area of original section; sq. ins. 774
Maximum load; lbs. per sq. in. orig. sect., 6,100
Area of fractured section; sq. in. 759
Reduction of area of cross section; per cent., 1.9
Modulus of elasticity 8,610,000

TENSION TEST.

Specimen, Bronze Alloy. Date, May 1, 1896.

Loads.	Micrometer Readings.				Mean.	Differences.	Remarks.
Actual.	1	2	1	2		Actual.	
500	.1117	.1117	.1056	.1056	.1086	.....	At 10,000 in. lbs. load the scale beam dropped.
1,000	.1119	.1118	.1058	.1058	.1088	.0002	
2,000	.1130	.1130	.1059	.1060	.1095	.0007	
3,000	.1139	.1138	.1064	.1064	.1101	.0006	Fractured outside measured section.
4,000	.1146	.1147	.1071	.1072	.1109	.0008	
5,000	.1152	.1153	.1080	.1080	.1116	.0007	
6,000	.1160	.1158	.1092	.1092	.1125	.0009	Specimen was distorted so badly at break that dimensions of fractured section could not be taken.
7,000	.1168	.1169	.1108	.1108	.1138	.0013	
8,000	.1182	.1182	.1135	.1136	.1159	.0021	
9,000	.1210	.1210	.1195	.1195	.1202	.0043	

Length between clamps	6″	Area of original section; sq. ins. . . .	.881
Dimensions of cross section	.52″ x 1.54″	Maximum load; lbs. per sq. in. orig. sect.,	13,900
Maximum load	11,150 lbs.	Reduction of area of cross section; per cent.	None apparent.
Elastic elongation for 1,000 to 5,000 lbs. load equals	.0028″	Modulus of elasticity	10,700,000

Tension Tests of Wire.

TENSION TESTS OF WIRE.

Date.	Specimen.	Diameter. (Inches.)	Area of cross section. (Square inches.)	Gauged length. (Ins.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Elastic elongation for difference of loads used in calculation of modulus of elasticity. (Inches.)	Modulus of elasticity. (Lbs. per sq. in.)
1895.							
Oct. 21	Annealed iron wire.	.135	.0143	100.00	.....	.....	.....
Oct. 23	Annealed iron wire.	.136	.0145	100.00	.....	.....	.....
Oct. 23	Annealed iron wire.	.135	.0143	100.00	95 to 190	.0289	23,000,000
Oct. 25	Annealed iron wire.	.136	.0145	100.00	76 to 152	.0205	25,500,000
Oct. 26	Annealed iron wire.	.135	.0143	100.00	95 to 190	.0283	23,500,000
Oct. 28	Annealed iron wire.	.136	.0145	100.00	.....	.....	.....
Oct. 30	Annealed iron wire.	.135	.0143	100.00	.....	.....	.....
Nov. 4	Common iron wire.	.110	.0095	100.00	95 to 190	.0330	30,300,000
Nov. 4	Common iron wire.	.109	.0093	100.00	95 to 190	.0370	27,500,000
Nov. 5	Common iron wire.	.110	.0095	100.00	380 to 532	.0699	22,900,000
Nov. 6	Common iron wire.	.113	.0100	100.00	171 to 247	.0301	25,200,000
Nov. 7	Common iron wire.	.080	.00503	100.00	95 to 190	.0700	27,000,000
Nov. 7	Common iron wire.	.080	.00503	100.00	152 to 247	.0712	26,500,000
Nov. 8	Common iron wire.	.079	.00490	100.00	133 to 247	.0875	26,600,000
Nov. 12	Common iron wire.	.079	.00490	100.00	152 to 304	.1189	26,100,000
Nov. 13	Common iron wire.	.079	.00490	100.00	190 to 247	.0440	26,400,000
Nov. 14	Common iron wire.	.080	.00503	100.00	171 to 209	.0279	27,100,000
Nov. 14	Annealed iron wire.	.081	.00515	100.00	76 to 152	.0554	26,600,000
Nov. 18	Annealed iron wire.	.082	.00528	100.00	.....	.....	.....
Nov. 25	Annealed iron wire.	.082	.00528	100.00	152 to 190	.0266	27,100,000
Nov. 27	Annealed iron wire.	.082	.00528	100.00	152 to 190	.0289	24,900,000
Dec. 5	Annealed iron wire.	.082	.00528	100.00	.....	.....	.....
Dec. 6	Annealed iron wire.	.082	.00528	100.00	152 to 190	.0276	26,100,000
Dec. 6	Annealed iron wire.	.082	.00528	100.00	152 to 190	.0265	27,000,000
Dec. 7	Common iron wire.	.167	.0219	100.00	.....	.....	.....
Dec. 9	Annealed iron wire.	.081	.00515	100.00	.....	.....	.....
Dec. 10	Annealed iron wire.	.082	.00528	100.00	.....	.....	.....
Dec. 12	Common iron wire.	.163	.0209	100.00	.....	.....	.....
Dec. 13	Common iron wire.	.163	.0209	100.00	.....	.....	.....
1896.							
Jan. 16	Piano wire, No. 13.	.0310	.000755	100.00	19 to 38	.0853	29,500,000
Jan. 18	Giese wire, No. 16.	.0356	.000995	100.00	19 to 57	.1293	29,500,000
Jan. 18	Piano wire, No. 22.	.0480	.001810	100.00	38 to 76	.0717	29,300,000
Jan. 18	Giese wire, No. 24.	.0547	.002350	100.00	38 to 114	.1098	29,400,000
Jan. 20	Hard drawn copper wire.	.1045	.00858	....	.....	.....	.....
Jan. 20	Hard drawn copper wire.	.1045	.00858	....	.....	.....	.....
Jan. 20	Hard drawn copper wire.	.1045	.00858	....	.....	.....	.....
Jan. 20	Hard drawn copper wire.	.1045	.00858	....	.....	.....	.....
Jan. 20	Hard drawn copper wire.	.1040	.00849	....	.....	.....	.....
Jan. 20	Hard drawn copper wire.	.1040	.00849	....	.....	.....	.....
Jan. 20	Hard drawn copper wire.	.1042	.00853	....	.....	.....	.....
Jan. 20	Hard drawn copper wire.	.1042	.00853	....	.....	.....	.....
Jan. 20	Hard drawn copper wire.	.1042	.00853	....	.....	.....	.....
Jan. 20	Hard drawn copper wire.	.1042	.00853	....	.....	.....	.....
Jan. 20	Hard drawn copper wire.	.1042	.00853	....	.....	.....	.....
Jan. 20	Hard drawn copper wire.	.1040	.00849	....	.....	.....	.....
Mar. 6	Hard drawn copper wire.	.1047	.00861	100.00	152 to 209	.0446	14,800,000
Mar. 10	Hard drawn copper wire.	.1050	.00866	100.00	152 to 228	.0688	12,800,000
Mar. 11	Hard drawn copper wire.	.1072	.00902	100.00	171 to 247	.0655	13,200,000
Mar. 13	Giese wire.	.0329	.000852	100.00	95 to 152	.2320	28,800,000
Mar. 16	Giese wire.	.0330	.000855	100.00	95 to 171	.2723	24,500,000
Mar. 17	Hard drawn copper wire.	.1048	.00863	100.00	190 to 266	.0831	10,800,000
Mar. 19	Hard drawn copper wire.	.1044	.00856	100.00	190 to 285	.0716	15,500,000
Mar. 20	Soft brass wire.	.072	.00407	100.00	.....	.....	.....
Mar. 27	Bessemer spring wire.	.0911	.00650	100.00	190 to 342	.0952	24,500,000
Mar. 27	Bessemer spring wire.	.0910	.00652	100.00	114 to 304	.1127	25,900,000
Mar. 31	Bessemer spring wire.	.0905	.00645	100.00	380 to 475	.0642	23,000,000
April 1	Bessemer spring wire.	.0911	.00652	100.00	190 to 380	.1206	24,200,000
April 2	Bessemer spring wire.	.0905	.00645	100.00	114 to 342	.1377	25,400,000

TENSION TESTS OF WIRE. — *Continued.*

Elastic limit. (Lbs.)	Elastic limit. (Lbs. per sq. in.)	Maximum load. (Lbs.)	Maximum load. (Lbs. per sq. in.)	Area of fractured section. (Sq. in.)	Reduction in area. (Per cent.)	Remarks.	Date.
							1895.
627	43,800	1,007	70,400	.00528	63.1		Oct. 21
...	.....	893	61,500	.00363	75.0		Oct. 23
570	39,800	874	61,100	.00724	49.4		Oct. 23
570	39,200	865	59,500	.00419	71.2		Oct. 25
513	35,800	646	45,100	.00332	76.8		Oct. 26
494	34,000	868	59,800	.00396	72.7		Oct. 28
...	.....	893	62,400	.00608	57.5		Oct. 30
608	64,000	864	90,900	.00454	52.3		Nov. 4
...	.....	959	103,000	.00332	64.4		Nov. 4
570	60,000	988	104,000	.00466	51.0		Nov. 5
684	68,200	940	93,700	.00396	60.5		Nov. 6
230	45,800	570	113,000	.00292	41.9		Nov. 7
285	56,700	570	113,000	.00246	51.0		Nov. 7
266	54,300	551	112,000	.00229	53.3		Nov. 8
361	73,600	589	120,000	.00353	28.1		Nov. 12
266	54,300	532	109,000	.00292	40.4		Nov. 13
..	.....	494	98,300	.00283	43.8		Nov. 14
...	.....	513	99,600	.00196	61.9		Nov. 14
266	50,400	494	93,500	.00189	64.3		Nov. 18
266	50,400	456	86,300	.00166	68.5		Nov. 25
285	54,000	475	89,900	.03255	51.7		Nov. 27
304	57,600	513	97,100	.00238	55.0	Fractured at lower grip.	Dec. 5
209	39,600	494	93,500	.00181	65.7	Fractured at lower grip.	Dec. 6
266	50,400	375	71,000	.00173	67.1	Fractured at lower grip.	Dec. 6
988	45,100	1,254	57,200	.00754	65.6	Fractured at lower grip.	Dec. 7
285	55,300	494	95,900	.00204	60.4		Dec. 9
228	43,200	494	93,500	.00132	75.0	Fractured at lower grip.	Dec. 10
836	40,100	1,406	67,400	.00899	56.9		Dec. 12
988	47,300	1,283	61,500	.00985	52.8	Fractured at lower grip.	Dec. 13
							1896.
...	.....	260	345,000	.....	....		Jan. 16
..	.....	294	296,000	.....	....		Jan. 18
...	.....	475	262,500	.....	....		Jan. 18
...	.....	670	285,030	.....	....		Jan. 18
...	.. ...	494	57,600	.....	....		Jan. 20
..	.....	494	57,600	.....	....		Jan. 20
...	.....	504	58,800	.....	....		Jan. 20
...	.....	513	59,800	.....	....		Jan. 20
...	.....	508	59,800	.....	....		Jan. 20
...	.....	504	59,300	.....	....		Jan. 20
...	.....	508	59,600	.....	....		Jan. 20
...	.....	513	60,200	.....	....		Jan. 20
...	.....	527	61,800	.....	....		Jan. 20
...	.....	508	59,600	.....	....		Jan. 20
...	.....	513	60,200	.....	....		Jan. 20
...	.....	499	58,700	.....	....		Jan. 20
456	53,000	532	61,800	.00427	50.5	Straight grip at upper end, round grip at lower end.	Mar. 6
304	35,100	494	57,100	.00442	49.0	Straight grip at upper end, round grip at lower end. Fractured at lower grip.	Mar. 10
304	33,700	532	58,900	.00604	33.1	Straight grip at each end. Fractured at lower grip.	Mar. 11
...	.....	285	334,000	.....	....		Mar. 13
...	.....	294	344,000	.....	....	Specimen contained soldered splice 3 inches long. It did not fracture at splice.	Mar. 16
418	48,500	437	50,700	.00455	47.3		Mar. 17
...	.....	513	59,900	.00353	58.8		Mar. 19
..	.....	223	54,800	.000940	76.9		Mar. 20
494	76,000	950	146,000	.00425	34.6		Mar. 27
456	69,900	974	149,000	.00316	51.6	Fractured at lower grip.	Mar. 27
513	79,600	969	150,000	.00374	42.0		Mar. 31
475	72,900	950	146,000	.00407	37.5	Fractured at lower grip.	April 1
...	.....	931	143,000	.00394	39.6	Fractured at lower grip.	April 2

TENSION TEST.

Specimen, No. 13 Piano Wire. Date, January 16, 1896.

Loads. Actual.	Micrometer Readings.	Differences. Actual.	Differences. Per 9.5 lbs.	Loads. Actual.	Micrometer Readings.	Differences. Actual.	Differences. Per 9.5 lbs.
19.0	.8823	....	....	123.5	.3965	.0465	.0465
38.0	.7970	.0853	.0427	133.0	.3495	.0470	.0470
57.0	.7113	.0857	.0428	142.5	.3000	.0495	.0495
76.0	.6247	.0866	.0433	152.0	.2484	.0516	.0516
85.5	.5808	.0439	.0439	161.5	.1972	.0512	.0512
95.0	.5357	.0451	.0451	171.0	.1452	.0520	.0520
104.5	.4895	.0462	.0462	180.5	.0922	.0530	.0530
114.0	.4430	.0465	.0465	190.0	.0350	.0572	.0572

Length between clamps . . . . . 100″
Dimension of cross section . . . . . .0310″ dia.
Maximum load . . . . . 260.3 lbs.
Elastic elongation for 19 to 38 lbs. load equals . . . . . .0853″
Area of original section; sq. ins. 000755
Maximum load; lbs. per sq. in. orig. sect., 344,900
Modulus of elasticity 29,510,000

TENSION TEST.

Specimen, No. 16 Giese Wire. Date, January 18, 1896.

Loads. Actual.	Micrometer Readings.	Differences. Actual.	Differences. Per 9.5 lbs.	Loads. Actual.	Micrometer Readings.	Differences. Actual.	Differences. Per 9.5 lbs.
19.0	.8138	....	....	152.0	.3496	.0349	.0349
57.0	.6845	.1293	.0323	161.5	.3141	.0355	.0355
66.5	.6520	.0325	.0325	171.0	.2776	.0365	.0365
76.0	.6194	.0326	.0326	180.5	.2407	.0369	.0369
85.5	.5870	.0324	.0324	190.0	.2025	.0382	.0382
95.0	.5536	.0334	.0334	199.5	.1637	.0388	.0388
104.5	.5199	.0337	.0337	209.0	.1230	.0407	.0407
114.0	.4867	.0332	.0332	218.5	.0809	.0421	.0421
123.5	.4529	.0338	.0338	228.0	.0370	.0439	.0439
133.0	.4185	.0344	.0344	232.75	.0115	.0255	.0510
142.5	.3845	.0340	.0340				

Length between clamps . . . . . 100″
Dimension of cross section . . . . . .0356″ dia.
Maximum load . . . . . 294.5 lbs.
Elastic elongation for 19 to 57 lbs. load equals . . . . . .1293″
Area of original section; sq. ins. 00099538
Maximum load; lbs. per sq. in. orig. sect., 295,860
Modulus of elasticity 29,525,000

TENSION TEST.

Specimen, No. 22 Piano Wire. Date, January 16, 1896.

Loads. Actual.	Micrometer Readings.	Differences. Actual.	Differences. Per 9.5 lbs.	Loads. Actual.	Micrometer Readings.	Differences. Actual.	Differences. Per 9.5 lbs.
38.0	.8961	....	....	266.0	.4334	Reset microm.	
76.0	.8244	.0717	.0179				
114.0	.7518	.0726	.0181	275.5	.4128	.0206	.0206
161.5	.6588	.0930	.0186	285.0	.3912	.0216	.0216
180.5	.6204	.0384	.0192	294.5	.3686	.0226	.0226
190.0	.6010	.0194	.0194	304.0	.3447	.0239	.0239
199.5	.5813	.0197	.0197	313.5	.3211	.0236	.0236
209.0	.5614	.0199	.0199	323.0	.2975	.0236	.0236
218.5	.5410	.0204	.0204	332.5	.2730	.0245	.0245
228.0	.5206	.0204	.0204	342.0	.2484	.0246	.0246
237.5	.5000	.0206	.0206	361.0	.1966	.0518	.0259
247.0	.4792	.0208	.0208	380.0	.1388	.0578	.0289
256.5	.4581	.0211	.0211				

Length between clamps . . . . . 100″
Dimension of cross section . . . . . .0480″ dia.
Maximum load . . . . . 475 lbs.
Elastic elongation for 38 to 76 lbs. load equals . . . . . .0717″

Area of original section; sq. ins. 001810
Maximum load; lbs. per sq. in. orig. sect., 262,500
Modulus of elasticity 29,290,000

TENSION TEST.

Specimen, No. 24 Giese Wire. Date, January 18, 1896.

Loads. Actual.	Micrometer Readings.	Differences. Actual, for each increase of load.	Differences. Total from first reading.	Differences. Elastic difference.	Differences. Elastic difference per 9.5 lbs.	Differences. Permanent set.
38.0	.8533					
114.0	.7431	.1102	.1102			
38.0	.8529			.1098	.0137	.0004
190.0	.6328	.1103	.2205			
38.0	.8512			.2184	.0137	.0021
266.0	.5174	.1154	.3359			
38.0	.8448			.3274	.0136	.0085
342.0	.3939	.1235	.4594			
38.0	.8334			.4395	.0137	.0199
418.0	.2620	.1319	.5913			
38.0	.8144			.5524	.0138	.0389
456.0	.1912	.0708	.6621			
494.0	.1087	.0825	.7446			

Length between clamps . . . . . 100″
Dimension of cross section . . . . . .0547″ dia.
Maximum load . . . . . 669.8 lbs.

Area of original section; sq. ins. 0023500
Maximum load; lbs. per sq. in. orig. sect., 285,030
Modulus of elasticity 29,347,000
Special modulus of elasticity between 38 and 114 lbs. 29,454,000

TENSION TEST.

Specimen, Giese Wire. Date, March 13, 1896.

Loads. Actual.	Micrometer Readings. 1	2	Mean.	Differences. Actual.	Remarks.
95	.8706	.8706	.8706	.....	
114	.7948	.7946	.7947	.0759	Fractured 1¼" from lower holder.
133	.7174	.7173	.7174	.0773	
152	.6386	.6386	.6386	.0788	
171	.5005	.5006	.5006	.1380	
190	.4603	.4603	.4603	.0403	
209	.3594	.3594	.3594	.1009	
228	.2573	.2573	.2573	.1021	

Length between clamps . . . . . 100"
Dimension of cross section . . . . . .0329" dia.
Maximum load . . . . . 285 lbs.
Elastic elongation for 57 lbs. load equals . .2320"

Area of original section; sq. ins. 000852
Maximum load; lbs. per sq. in. orig. sect., 334,000
Modulus of elasticity 28,800,000

TENSION TEST.

Specimen, Giese Wire. Date, March 16, 1896.

Loads. Actual.	Micrometer Readings. 1	2	Mean.	Differences. Actual.	Remarks.
57	.8573	.8574	.85735	.....	
76	.7988	.7990	.79890	.05845	Soldered splice 3" long.
95	.6882	.6884	.68830	.11060	
114	.5952	.5952	.59520	.09310	
133	.5055	.5050	.50525	.08995	Did not fail at splice.
152	.4161	.4159	.4160	.08925	
171	.3205	.3204	.32045	.09555	The increase in the stretch at 95 lbs. load
190	.2206	.2208	.2207	.09975	is probably due to splice drawing tight.

Length between clamps . . . . . 100"
Dimension of cross section . . . . . .033" dia.
Maximum load . . . . . 294.5 lbs.

Area of original section; sq. ins. 000855
Maximum load; lbs. per sq. in. orig. sect., 344,000

Torsion Machine.

A description of the machine upon which these tests were made will be found in Vol. VI, No. 4, of the *Technology Quarterly*. Since the publication of that description, the measuring apparatus, which proved unsatisfactory, has been replaced by the following:

Two telescopes mounted on cast-iron frames are clamped to the specimen, one at each end of the measured section, and focused on two vertical scales placed 500 inches from the axis of the specimen, measured in a line perpendicular to it at each telescope. The scales are graduated to tenths of an inch from a zero below the level of the axis of the specimen. The reading of the level of the center of the specimen on each scale was carefully determined once for all.

The angle which the axis of the telescope makes with the horizontal $= \tan^{-1} \{$reading of telescope on scale $-$ (reading of level of center of specimen on scale $+$ height of center of telescope above center of specimen)$\} \div 500$.

With the initial load on the specimen, the telescopes are set to read at the tops of the scales. Check readings are taken on each telescope. The mean of each pair of check readings, corrected by subtracting the difference in height between the center of the telescope and the zero of the scale, gives the ordinate of the tangent of the angle which the axis of the telescope makes with the horizontal. The angle itself is found from a table of natural tangents and recorded on the log. This operation is repeated at every load. Then the difference between each two successive angles of each telescope with the horizontal is the angle through which the telescope moves under each increment of load, while the difference between the angle through which the power end telescope moves under an increment of load and the angle through which the scale end telescope moves under that increment is the angle of twist of the specimen in its gauged length.

The maximum angle of each telescope with the horizontal is about 9° 30′ when it is reading on the top of the scale. When it has turned down to an angle of from 2° to 5°, it must be reset to read on the top of the scale again, as other apparatus in the room prevents lower readings. The errors of this apparatus have been carefully determined and found to be insignificant within the limit of accuracy kept in the angles, which are recorded to the nearest ten seconds.

The spring balance which was formerly used to weigh the moment

of twist of the specimen has been replaced by a scale beam graduated directly in inch pounds, and reading to 90 inch pounds by actual division. As these smallest divisions are about $\frac{1}{8}$ inch in length, however, the load can be weighed by estimation with greater precision than 90 inch pounds. The tests of small specimens and of wire were made on a similar machine mounted on the bed of a lathe. The weighing beam of this machine is graduated so that it is possible to weigh twisting moments to one tenth of an inch pound.

TORSION TESTS ON WIRE.

Date.	Specimen.	Diameter of specimen. (Inches.)	Length of specimen between jaws. (Inches.)	Maximum twisting moment. (Inch pounds.)	Apparent outside fiber stress, calculated from max. twisting moment. (Lbs. per. sq. in.)	Turns of specimen between jaws at fracture.	Average turns per inch at fracture.	Remarks.
1896.								
Mar. 6	Hard drawn copper wire.	.0141	12.00	9.4	42,600	70.75	5.90	
Mar. 10	Hard drawn copper wire.	.1050	12.00	14.0	61,600	87.50	7.29	
Mar. 10	Common iron wire.	.194	12.00	108.4	75,600	23.00	1.92	Twisted in sections from $\frac{1}{8}$ in. to 4 in. long, and separated by sharply defined lines, alternately twisted closely and almost straight. No twisted section was more than 1 in. long.
Mar. 13	Common iron wire.	.193	12.00	112.5	81,000	5.00	0.42	
Mar. 16	Common iron wire.	.193	24.00	113.8	80,600	90.50	3.77	
Mar. 19	Spring brass wire.	.0831	12.00	11.3	104,000	5.00	0.42	
Mar. 19	Spring brass wire.	.0830	12.00	10.0	92,400	4.00	0.33	
Mar. 19	Spring brass wire.	.0830	12.00	13.0	120,000	7.75	0.65	
Mar. 25	Bessemer spring wire.	.0910	12.00	23.0	161,000	5.25	0.44	Specimen buckled badly and twisted only at scale end grip.
Mar. 26	Bessemer spring wire.	.0900	12.00	21.5	150,000	4.75	0.40	Specimen buckled badly and twisted only at scale end grip.
Mar. 27	Bessemer spring wire.	.0912	6.00	27.8	187,000	5.00	0.83	
Mar. 27	Bessemer spring wire.	.0912	6.00	25.9	174,000	11.50	1.92	
Mar. 30	Bessemer spring wire.	.0910	6.00	26.5	179,000	4.25	0.71	
Mar. 30	Bessemer spring wire.	.0908	6.00	26.1	178,000	11.50	1.92	
April 1	Bessemer spring wire.	.0908	6.00	24.5	170,000	17.00	2.83	
April 2	Bessemer spring wire.	.0905	6.00	20.6	142,000	7.50	1.25	
April 4	Bessemer spring wire.	.0910	6.00	26.0	176,000	9.00	1.50	
April 4	Bessemer spring wire.	.0910	6.00	26.0	176,000	8.50	1.42	

TORSION TESTS.

Date.	Specimen.	Diameter. (Inches.)	Distance between grips. (Inches.)	Gauged length. (Ins.)	Elastic limit. (Inch lbs.)	Outside fiber stress at elastic limit. (Lbs. per sq. in.)	Maximum twisting moment. (Inch lbs.)	Apparent outside fiber stress calculated from max. twisting moment. (Lbs. per sq. in.)	Shearing modulus of elasticity. (Lbs. per sq. in.)	No. of turns between grips at fracture.	Turns per foot between grips at fracture.	Time of breaking after passing elastic limit.	Time of one revolution of power end chuck after passing elastic limit.	Location of break.	Remarks.
1895.												h. m.	m. s.		
Oct. 24	Bessemer steel.	1.49	60.0	40.00	.....	.....	43,920	66,280	11,800,000	8.6	1.72	.....	.....	6 in. from power end grip.	
Oct. 25	Bessemer steel.	1.50	58.0	40.00	14,400	21,700	44,640	67,400	11,700,000	13.3	2.75	.....	.....	6 in. from power end grip.	
Oct. 30	Bessemer steel.	1.50	57.5	40.00	17,000	25,600	44,820	67,600	11,900,000	11.5	2.40	.....	.....	At power end grip.	
Nov. 1	Bessemer steel.	1.50	57.6	40.00	17,000	25,600	45,810	69,100	11,900,000	9.9	2.03	.....	.....		
Nov. 4	Bessemer steel.	1.50	59.0	40.00	16,000	24,100	45,450	68,600	11,600,000	10.8	2.20	.....	.....		
Nov. 5	Refined iron.	1.75	61.1	40.00	18,000	17,100	56,150	53,400	11,200,000	7.1	1.39	.....	.....		
Nov. 11	Refined iron.	1.75	64.0	40.00	14,400	13,700	55,350	52,600	11,200,000	8.7	1.63	.....	7, 0	3 in. from scale end grip.	
Nov. 12	Refined iron.	1.72	64.5	40.00	14,400	14,300	45,090	44,900	11,800,000	5.4	1.00	.....	7, 0		
Nov. 13	Refined iron.	1.75	61.0	40.00	14,400	13,700	53,360	50,700	11,500,000	6.1	1.20	.....	.....	13 in. from scale end grip.	
Nov. 18	Swedish iron.	2.01	81.5	60.00	18,000	11,300	83,180	52,200	11,500,000	20.8	3.06	.....	.....	At power end grip.	
Nov. 20	Swedish iron.	2.01	79.0	60.00	23,000	14,400	83,340	52,300	11,600,000	20.7	3.14	2, 30	7, 15	At power end grip.	
Nov. 26	Swedish iron.	2.00	77.5	60.00	19,800	12,600	79,650	50,700	11,400,000	19.1	2.96	2, 15	7, 04	At scale end grip.	
Dec. 2	Swedish iron.	2.01	76.7	60.00	19,800	12,600	82,530	52,500	11,200,000	24.3	3.80	1, 30	3, 45	At power end grip.	
Dec. 5	Swedish iron.	2.00	80.5	60.00	23,400	14,900	84,330	53,700	11,700,000	22.3	3.32	1, 45	.....	At power end grip.	
Dec. 10	Swedish iron.	2.00	75.0	60.00	23,400	14,900	84,960	54,100	11,700,000	18.1	2.90	1, 05	3, 31	12 in. from scale end grip.	
Dec. 13	Refined iron.'	1.75	63.2	40.00	16,200	15,400	57,080	54,200	.....	10.2	1.94	0, 35	2, 53	30 in. from scale end grip.	
Dec. 16	Bessemer steel.	1.50	58.8	40.00	18,000	27,200	44,460	67,100	11,700,000	10.5	2.14	0, 40	3, 35	At power end grip.	
1896.															
Mar. 5	Bessemer steel.	1.50	59.1	40.00	16,200	24,400	45,000	67,900	11,500,000	13.2	2.68	.....	3, 30		
Mar. 10	Bessemer steel.	1.50	58.2	40.00	18,000	27,200	44,920	67,800	11,700,000	10.8	2.22	0, 40	3, 49	At power end grip.	
Mar. 13	Refined iron.	1.74	63.0	40.00	16,200	15,400	55,710	52,900	11,300,000	7.8	1.49	.....	5, 34		
Mar. 19	Composition.	1.52	28.0	20.00	4,500	6,530	23,130	33,500	4,810,000	3.6	1.54	1, 0	17, 08	8 in. from power end grip.	85% copper, 7% spelter, 8% tin.
Mar. 23	Composition.	1.51	27.0	20.00	5,040	7,460	28,800	42,600	5,210,000	5.0	2.22	1, 12	14, 20	At power end grip.	
Mar. 25	Brass.	1.51	28.0	20.00	3,600	5,220	17,460	25,900	4,380,000	3.5	1.50	0, 48	13, 43	Center.	
Mar. 26	Bessemer steel.	1.50	58.0	40.00	18,000	27,200	45,540	68,700	11,700,000	11.4	2.36	0, 50	4, 23	At power end grip.	
Mar. 27	Swedish iron.	2.02	79.0	60.00	23,400	14,300	82,350	50,400	11,300,000	21.0	3.19	2, 16	6, 29	At power end grip.	

TORSION TEST.

Specimen, Bessemer Steel. Date, October, 24, 1895.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.	Remarks.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.		
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
1,800	92.49	92.50	91.48	91.49	83.49	83.58	9, 28, 50	9, 29, 26	.. .. ..	.. .. ..	.. .. ..	
2,700	86.15	86.18	88.22	88.24	77.16	80.31	8, 46, 34	9, 7, 30	0, 42, 16	0, 21, 56	0, 20, 20	
3,600	78.08	78.09	83.29	83.31	69.08	75.40	7, 52, 0	8, 34, 32	0, 54, 34	0, 32, 58	0, 21, 36	Specimen fractured 6″ from power end grip.
4,500	69.81	69.81	78.30	78.31	60.81	70.40	6, 56, 4	8, 0, 54	0, 55, 56	0, 34, 38	0, 21, 18	
5,400	62.50	62.51	73.95	73.93	53.50	66.04	6, 6, 28	7, 31, 26	0, 49, 36	0, 29, 28	0, 20, 8	
6,300	54.80	54.80	68.99	69.00	45.80	61.09	5, 14, 2	6, 58, 0	0, 52, 26	0, 33, 26	0, 19, 0	
7,200	46.21	46.21	63.70	63.71	37.21	55.80	4, 15, 22	6, 22, 6	0, 59, 40	0, 35, 54	0, 23, 46	
7,200	92.87	92.88	93.05	93.03	83.87	85.14	9, 31, 22	9, 39, 48	.. .. ..	.. .. ..	.. .. ..	
8,100	86.58	86.59	89.51	89.51	77.58	81.61	8, 49, 12	9, 16, 12	0, 42, 10	0, 23, 36	0, 18, 34	
9,900	72.28	72.27	81.60	81.60	63.27	73.70	7, 12, 44	8, 23, 61	1, 37, 28	0, 53, 6	0, 44, 22	
11,700	59.08	59.08	74.59	74.60	50.08	66.69	5, 43, 10	7, 35, 52	1, 29, 34	0, 47, 14	0, 42, 20	
13,500	46.08	46.10	67.60	67.61	37.09	59.70	4, 14, 12	6, 48, 34	1, 28, 58	0, 47, 18	0, 41, 40	
15,300	33.39	33.41	60.90	65.90	24.40	53.00	2, 47, 46	6, 3, 2	1, 26, 26	0, 45, 32	0, 40, 54	
15,300	76.40	76.40	84.00	84.00	67.40	76.10	7, 40, 38	8, 39, 14	.. .. ..	.. .. ..	.. .. ..	
17,100	64.35	64.33	77.81	77.80	55.34	69.90	6, 19, 56	7, 57, 3	1, 20, 42	0, 41, 42	0, 39, 0	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.10″
Length of specimen between jaws	60.0″
Dimension of cross section	1.49″ dia.
Length of specimen between telescopes	40.00″
Maximum twisting moment	43,920 in. lbs.
Number of turns of specimen between jaws at fracture	8.6
Outside fiber stress at elastic limit	66,280 lbs. per sq. in.
Angle of twist between 1,800 in. lbs. and 7,200 in. lbs.	2° 6′ 8″
Shearing modulus of elasticity between 1,800 in. lbs. and 7,200 in. lbs.	11,800,000
Average number of turns of specimen per foot at fracture	1.72

TORSION TEST.

Specimen, Bessemer Steel. Date, October 30, 1895.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.	Remarks.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.		
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
2,700	76.75	76.77	80.42	80.41	67.76	72.51	7, 43, 0	8, 15, 30	.. ..	.....	.. ..	Specimen fractured at power end jaw.
3,600	68.04	68.05	74.80	74.80	59.04	66.90	6, 44, 10	7, 37, 20	0, 58, 50	0, 38, 0	0, 20, 50	
4,500	57.92	57.94	67.72	67.71	48.93	59.81	5, 35, 20	6, 49, 20	1, 8, 50	0, 48, 0	0, 20, 50	
5,400	49.31	49.33	62.41	62.42	40.32	54.51	4, 36, 40	6, 13, 20	0, 58, 40	0, 36, 0	0, 22, 40	
5,400	93.11	93.11	90.00	90.00	84.11	82.10	9, 33, 0	9, 19, 30	... ...	.....	.. ..	
6,300	85.50	85.52	85.10	85.10	76.51	77.20	8, 42, 0	8, 46, 40	0, 51, 0	0, 32, 50	0, 18, 10	
7,200	76.90	76.90	79.75	79.75	67.90	71.85	7, 44, 0	8, 9, 30	0, 58, 0	0, 37, 10	0, 20, 50	
8,100	69.20	69.18	75.20	75.20	60.18	67.30	6, 51, 50	7, 40, 0	0, 52, 10	0, 29, 30	0, 22, 40	
9,000	60.98	60.96	70.10	70.08	51.97	62.19	5, 58, 0	7, 4, 40	0, 53, 50	0, 35, 20	0, 18, 30	
9,900	52.78	52.80	64.83	64.82	43.79	56.92	5, 0, 20	6, 29, 40	0, 57, 40	0, 35, 0	0, 22, 40	
9,900	92.10	92.10	84.70	84.70	83.10	76.80	9, 26, 10	8, 44, 0	.. ..	....	.. ..	
11,700	79.31	79.31	77.92	77.90	70.31	70.01	8, 0, 20	7, 58, 10	1, 25, 50	0, 45, 50	0, 40, 0	
12,600	72.58	72.60	74.60	74.60	63.59	66.70	7, 14, 50	7, 35, 40	0, 45, 30	0, 22, 30	0, 23, 0	
13,500	66.80	66.80	71.80	71.80	57.80	63.90	6, 35, 40	7, 17, 0	0, 39, 10	0, 18, 40	0, 20, 30	
14,400	60.58	60.60	68.80	68.80	51.59	60.90	5, 52, 30	6, 56, 40	0, 42, 10	0, 20, 20	0, 21, 50	
15,300	54.40	54.40	65.60	65.60	45.40	57.70	5, 11, 20	6, 35, 0	0, 42, 10	0, 21, 40	0, 20, 30	
16,200	48.48	48.51	62.80	62.80	39.49	54.90	4, 31, 0	6, 16, 0	0, 40, 20	0, 19, 0	0, 21, 20	
16,200	92.10	92.10	80.25	80.23	81.10	72.34	9, 12, 50	8, 14, 0	.. ..	.....	.. ..	
17,100	85.50	85.50	77.39	77.40	74.50	69.49	8, 28, 30	7, 54, 50	0, 44, 20	0, 19, 10	0, 25, 10	
18,000	60.15	60.15	72.50	72.52	51.15	64.60	5, 50, 30	7, 22, 40	2, 38, 0	0, 32, 10	2, 5, 50	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.10″
Length of specimen between jaws	57.5″
Dimension of cross section	1.50″ dia.
Length of specimen between telescopes	40.00″
Elastic limit in torsion	17,000 in. lbs.
Maximum twisting moment	44,820 in. lbs.
Number of turns of specimen between jaws at fracture	11.5
Outside fiber stress at elastic limit	25,600 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	67,600 lbs. per sq. in.
Angle of twist between 3,600 in. lbs. and 9,900 in. lbs.	2° 26′ 20″
Shearing modulus of elasticity between 3,600 in. lbs. and 9,900 in. lbs.	11,900,000
Average number of turns of specimen per foot at fracture	2.40

TORSION TEST.

Specimen, Bessemer Steel. Date, November 1, 1895.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.	
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″
1,800	92.00	92.01	91.60	91.60	83.00	83.70	9, 25, 30	9, 30, 10	.. ..	.. ..	.. ..
3,600	71.79	71.80	77.43	77.44	62.79	69.54	7, 9, 30	7, 55, 0	2, 16, 0	1, 35, 10	0, 40, 50
5,400	57.29	57.31	69.14	69.12	48.30	61.23	5, 31, 0	6, 59, 0	1, 38, 30	0, 56, 0	0, 43, 30
5,400	88.70	88.71	90.59	90.59	79.70	82.68	9, 3, 20	9, 23, 20	.. ..	.. ..	.. ..
7,200	73.81	73.80	81.91	81.91	64.80	74.01	7, 23, 0	8, 25, 10	1, 40, 20	0, 58, 10	0, 42, 10

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.10″
Length of specimen between jaws	57.⅜″
Dimension of cross section	1.50″ dia.
Length of specimen between telescopes	40.00″
Elastic limit in torsion	17,000 in. lbs.
Maximum twisting moment	45,810 in. lbs.
Number of turns of specimen between jaws at fracture	9.9
Outside fiber stress at elastic limit	25,600 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	69,100 lbs. per sq. in.
Angle of twist between 1,800 in. lbs. and 7,200 in. lbs.	2° 5′ 30″
Shearing modulus of elasticity between 1,800 in. lbs. and 7,200 in. lbs.	11,900,000
Average number of turns of specimen per foot at fracture	2.03

TORSION TEST.

Specimen, Refined Iron. Date, November 5, 1895.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.	Remarks.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.		
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
3,600	94.12	94.12	90.11	90.11	86.07	80.96	9, 46, 0	9, 11, 50	.....	.....	.. ..	
7,200	77.50	77.50	80.59	80.59	69.45	71.44	7, 54, 30	8, 7, 50	1, 51, 30	1, 4, 0	0, 47, 30	At 21,600 in. lbs. load the scale beam dropped.
10,800	58.50	58.50	68.50	68.50	50.45	59.35	5, 45, 40	6, 46, 10	2, 8, 50	1, 21, 40	0, 47, 10	
10,800	93.59	93.59	90.93	90.93	85.54	81.78	9, 42, 30	9, 17, 30	.....	.....	.. ..	
14,400	76.50	76.50	81.17	81.17	68.45	72.02	7, 47, 40	8, 11, 50	1, 54, 50	1, 5, 40	0, 49, 10	
18,000	56.39	56.39	70.70	70.70	48.34	61.55	5, 31, 20	7, 1, 0	2, 60, 20	1, 10, 50	0, 49, 30	
18,000	93.33	93.33	93.24	93.24	85.28	84.09	9, 40, 50	9, 32, 50	.....	.....	.. ..	
21,600	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.25″
Length of specimen between jaws	61.1″
Dimension of cross section	1.75″ dia.
Length of specimen between telescopes	40.00″
Elastic limit in torsion	18,000 in. lbs.
Maximum twisting moment	56,150 in. lbs.
Number of turns of specimen between jaws at fracture	7.1
Outside fiber stress at elastic limit	17,100 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	53,400 lbs. per sq. in.
Angle of twist between 3,600 in. lbs. and 14,400 in. lbs.	2° 23′ 50″
Shearing modulus of elasticity between 3,600 lbs. and 14,400 in. lbs.	11,200,000
Average number of turns of specimen per foot at fracture	1.39

TORSION TEST.

Specimen, Refined Iron Bar. Date, November 11, 1895.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.	Remarks.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.		
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
3,600	93.50	93.49	90.11	90.10	84.35	82.06	9, 34, 30	9, 19, 10	.....	.....	.....	
7,200	70.68	70.69	74.34	74.32	61.54	66.28	7, 1, 0	7, 33, 0	2, 33, 30	1, 46, 10	0, 47, 20	At 19,800 in. lbs. load
10,800	51.10	51.09	61.87	61.85	41.95	53.81	4, 47, 40	6, 8, 30	2, 13, 20	1, 24, 30	0, 48, 50	the scale beam dropped.
10,800	94.34	94.34	91.89	91.90	85.19	83.85	9, 40, 10	9, 31, 10	.....	.....	.....	
12,600	85.41	85.40	86.55	86.55	76.26	78.50	8, 40, 20	8, 55, 20	0, 59, 50	0, 35, 50	0, 24, 0	Specimen fractured
14,400	76.10	76.12	81.11	81.10	66.96	73.06	7, 37, 40	8, 18, 50	1, 2, 40	0, 36, 30	0, 26, 10	3″ from scale end jaw.
16,200	65.10	65.12	74.74	74.74	55.96	66.69	6, 23, 10	7, 35, 50	1, 14, 30	0, 43, 0	0, 31, 30	
18,000	51.90	51.90	68.09	68.11	42.75	60.05	4, 53, 10	6, 50, 50	1, 30, 0	0, 45, 0	0, 45, 0	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.25″
Length of specimen between jaws	64.00″
Dimension of cross section	1.75 in. dia.
Length of specimen between telescopes	40.00″
Elastic limit in torsion	14,400 in. lbs.
Maximum twisting moment	55,350 in. lbs.
Number of turns of specimen between jaws at fracture	8.7
Outside fiber stress at elastic limit	13,700 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	52,600 lbs. per sq. in.
Angle of twist between 3,600 in. lbs. and 12,600 in. lbs.	2° 0′ 10″
Shearing modulus of elasticity between 3,600 in. lbs. and 12,600 in. lbs.	11,200,000
Average number of turns of specimen per foot at fracture	1.63

TORSION TEST.

Specimen, Refined Iron. Date, November 12, 1895.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.	Remarks.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.		
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
3,600	89.89	89.89	90.54	90.54	80.74	82.49	9, 10, 10	9, 20, 10	.....	.....	.....	
5,400	79.90	79.90	83.90	83.90	70.75	75.85	8, 2, 10	8, 37, 30	1, 8, 0	0, 42, 40	0, 25, 20	At 19,800 in. lbs.
7,200	68.65	68.65	76.32	76.31	59.50	68.27	6, 47, 10	7, 46, 30	1, 15, 0	0, 51, 00	0, 24, 0	load the scale beam
9,000	58.66	58.66	69.75	69.75	49.51	61.70	5, 39, 20	7, 2, 0	1, 7, 50	0, 44, 30	0, 23, 20	dropped.
10,800	49.07	49.09	63.72	63.70	39.93	55.66	4, 34, 0	6, 21, 10	1, 5, 20	0, 40, 50	0, 24, 30	
12,600	39.61	39.61	57.83	57.83	30.46	49.78	3, 29, 10	5, 41, 10	1, 4, 50	0, 40, 0	0, 24, 50	
12,600	90.14	90.14	89.02	89.02	80.99	80.97	9, 12, 0	9, 11, 50	.....	.....	.....	
14,400	81.51	81.52	84.08	84.08	72.37	76.03	8, 14, 10	8, 38, 30	0, 57, 50	0, 33, 20	0, 24, 30	
16,200	71.13	71.14	78.13	78.11	61.99	70.07	7, 4, 0	7, 58, 40	1, 10, 10	0, 39, 50	0, 30, 20	
18,000	59.60	59.62	71.90	71.90	50.46	63.85	5, 45, 50	7, 16, 40	1, 18, 10	0, 42, 0	0, 36, 10	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90″; scale end, 2.80″
Height of center of telescope above center of test piece	5.25″
Length of specimen between jaws	64.5″
Dimension of cross section	1.72 in. dia.
Length of specimen between telescopes	40.00″
Elastic limit in torsion	14,400 in. lbs.
Maximum twisting moment	45,090 in. lbs.
Number of turns of specimen between jaws at fracture	5.4
Outside fiber stress at elastic limit	14,300 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	44,900 lbs. per sq. in.
Angle of twist between 3,600 in. lbs. and 12,600 in. lbs.	2° 2′ 0″
Shearing modulus of elasticity between 3,600 in. lbs. and 12,600 in. lbs.	11,800,000
Average number of turns of specimen per foot at fracture	1.00

TORSION TEST.

Specimen, Refined Iron. Date, November 13, 1895.

Twisting moment.	Scale Readings. Power End. 1	Power End. 2	Scale End. 1	Scale End. 2	Corrected Mean. Power End.	Scale End.	Angles Corresponding. Power End. ° ′ ″	Scale End. ° ′ ″	Differences. Power End. ° ′ ″	Scale End. ° ′ ″	Angle of Twist. ° ′ ″	Remarks.
1,800	93.23	93.23	89.91	89.92	84.08	81.86	9, 32, 40	9, 17, 50	.....	.....	.....	
3,600	84.52	84.54	84.62	84.61	75.38	76.56	8, 34, 20	8, 42, 20	0, 58, 20	0, 35, 30	0, 22, 50	Specimen fractured 13″ from power end jaw.
5,400	73.62	73.63	77.22	77.20	64.47	69.16	7, 20, 50	7, 52, 30	0, 73, 30	0, 49, 50	0, 23, 40	
7,200	63.83	63.84	70.90	70.90	54.68	62.85	6, 14, 30	7, 9, 50	0, 66, 20	0, 42, 40	0, 23, 40	
9,000	55.35	55.34	65.93	65.92	46.19	57.87	5, 16, 40	6, 36, 10	0, 57, 50	0, 33, 40	0, 24, 10	
10,800	47.10	47.11	61.12	61.12	37.95	53.07	4, 20, 30	6, 3, 30	0, 56, 10	0, 32, 40	0, 23, 30	
12,600	38.71	38.72	56.21	56.22	29.56	48.16	3, 23, 0	5, 30, 10	0, 57, 30	0, 33, 20	0, 24, 10	
12,600	91.86	91.86	89.40	89.41	82.71	81.35	9, 23, 30	9, 14, 30	.....	.....	.....	
14,400	83.70	83.72	84.87	84.88	74.56	76.82	8, 28, 50	8, 44, 10	0, 54, 40	0, 30, 20	0, 24, 20	
16,200	74.70	74.70	80.09	80.07	65.55	72.03	7, 28, 10	8, 11, 50	1, 0, 40	0, 32, 20	0, 28, 20	
18,000	64.32	64.33	75.12	75.14	55.17	67.08	6, 17, 50	7, 38, 30	1, 10, 20	0, 33, 20	0, 37, 0	
19,800	46.67	46.65	68.39	68.41	37.51	60.35	4, 17, 20	6, 53, 0	2, 0, 30	0, 45, 30	1, 15, 0	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90″; scale end, 2.80″
Height of center of telescope above center of test piece	5.25″
Length of specimen between jaws	61.00″
Dimension of cross section	1.75 in. dia.
Length of specimen between telescopes	40.00″
Elastic limit in torsion	14,400 in. lbs.
Maximum twisting moment	53,360 in. lbs.
Number of turns of specimen between jaws at fracture	6.1
Outside fiber stress at elastic limit	13,700 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	50,700 lbs. per sq. in.
Angle of twist between 1,800 in. lbs. and 10,800 in. lbs.	1° 57′ 10″
Shearing modulus of elasticity between 1,800 in. lbs. and 10,800 in. lbs.	11,500,000
Average number of turns of specimen per foot at fracture	1.20

TORSION TEST.

Specimen, Swedish Iron. Date, November 18, 1895.

Twisting moment.	Scale Readings. Power end. 1	Power end. 2	Scale end. 1	Scale end. 2	Corrected Mean. Power end.	Scale end.	Angles Corresponding Power end. ° ′ ″	Scale end. ° ′ ″	Differences. Power end. ° ′ ″	Scale end. ° ′ ″	Angle of twist. ° ′ ″	Remarks.
3,600	91.21	91.20	86.75	86.76	81.84	78.49	9, 17, 40	8, 55, 20	.....	.....	.....	
7,200	73.27	73.27	74.80	74.80	63.91	66.54	7, 17, 0	7, 34, 50	2, 0, 40	1, 20, 30	0, 40, 10	Specimen fractured at power end jaw.
10 800	59 58	59.56	66.97	66.96	50.21	58.70	5, 44, 0	6, 41, 40	1, 33, 0	0, 53, 10	0, 39, 50	
14,400	46.04	46.03	59.31	59.30	36.67	51.04	4, 11, 40	5, 49, 40	1, 32, 20	0, 52, 0	0, 40, 20	
18,000	33.40	33.40	52.56	52.54	24 04	44.29	2, 45, 10	5, 3, 40	1, 26, 30	0, 46, 0	0, 40, 30	
18,000	80.87	80.86	83.33	83.32	71.50	75.06	8, 8, 20	8, 32, 5	.....	.....	.....	
21,600	67.68	67.69	78.67	78.68	58.32	74.41	6, 39, 10	8, 27, 50	1, 29, 10	0, 4, 15	1, 24, 55	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.46″
Length of specimen between jaws	81.5″
Dimension of cross section	2.01 in. dia.
Length of specimen between telescopes	60.00″
Elastic limit in torsion	18,000 in. lbs.
Maximum twisting moment	83,180 in. lbs.
Number of turns of specimen between jaws at fracture	20.8
Outside fiber stress at elastic limit	11,300 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	52,200 lbs. per sq. in.
Angle of twist between 3,600 in. lbs. and 14,400 in. lbs.	2° 0′ 20″
Shearing modulus of elasticity between 3,600 in. lbs. and 14,400 in. lbs.	11,500,000
Average number of turns of specimen per foot at fracture	3.06

TORSION TEST.

Specimen, Swedish Iron. Date, November 20, 1895.

Twisting moment.	Scale Readings. Power end. 1	Power end. 2	Scale end. 1	Scale end. 2	Corrected Mean. Power end.	Scale end.	Angles Corresponding. Power end. ° ′ ″	Scale end. ° ′ ″	Differences. Power end. ° ′ ″	Scale end. ° ′ ″	Angle of twist. ° ′ ″	Remarks.
3,600	79.72	79.72	76.59	76.61	70.36	68.34	8, 0, 40	7, 47, 0	.....	.....	.....	
7,200	69.99	69.99	72.72	72.70	60.63	64.45	6, 54, 50	7, 20, 40	1, 5, 50	0, 26, 20	0, 39, 30	At 25,200 in. lbs. load the scale beam dropped.
10,800	60.39	60.41	68.98	68.98	51.04	60.72	5, 49, 40	6, 55, 30	1, 5, 10	0, 25, 10	0, 40, 0	
14,400	49.71	49.71	64.17	64.19	40.35	55.92	4, 36, 50	6, 23, 0	1, 12, 50	0, 32, 30	0, 40, 20	
16,200	43.06	43.08	60.46	60.45	33.71	52.20	3, 51, 20	5, 57, 40	0, 45, 30	0, 25, 20	0, 20, 10	
18,000	37.50	37.50	57.76	57.78	28.15	49.51	3, 13, 20	5, 39, 40	0, 38, 0	0, 18, 0	0, 20, 0	Specimen fractured at power end jaw.
18,000	92.90	92.91	84.62	84.64	83.54	76.37	9, 29, 10	8, 41, 0	.....	.....	.....	
19,800	86.91	86.91	81.66	81.66	77.55	73.40	8, 49, 0	8, 21, 0	0, 40, 10	0, 20, 0	0, 20, 10	
21,600	80.99	80.98	78.83	78.83	71.63	70.57	8, 9, 10	8, 2, 0	0, 39, 50	0, 19, 0	0, 20, 50	
23,400	74.60	74.60	75.53	75.52	65 24	67.27	7, 26, 0	7, 39, 50	0, 43, 10	0, 22, 10	0, 21, 0	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.25″
Length of specimen between jaws	79.0″
Dimension of cross section	2.01 in. dia.
Length of specimen between telescopes	60.00″
Elastic limit in torsion	23,000 in. lbs.
Maximum twisting moment	83,340 in. lbs.
Number of turns of specimen between jaws at fracture	20.7
Outside fiber stress at elastic limit	14,400 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	52,300 lbs. per sq. in.
Angle of twist between 3,600 in. lbs. and 18,000 in. lbs.	2° 40′ 0″
Shearing modulus of elasticity between 3,600 in. lbs. and 18,000 in. lbs.	11,600,000
Average number of turns of specimen per foot at fracture	3.14

TORSION TEST.

Specimen, Swedish Iron. Date, November 26, 1895.

Twisting moment.	Scale Readings. Power end. 1	Power end. 2	Scale end. 1	Scale end. 2	Corrected Mean. Power end.	Scale end.	Angles Corresponding. Power end. ° ′ ″	Scale end. ° ′ ″	Differences. Power end. ° ′ ″	Scale end. ° ′ ″	Angle of Twist. ° ′ ″	Remarks.
3,600	92.23	92.24	91.07	91.06	82.87	82.80	9, 24, 40	9, 24, 10	.....	.....	.....	
7,200	72.79	72.79	77.62	77.61	63.43	69.35	7, 13, 48	7, 53, 50	2, 10, 52	1, 30, 20	0, 40, 32	Specimen fractured at scale end jaw.
10,800	56.40	56.40	67.19	67.18	47.04	58.92	5, 22, 30	6, 43, 10	1, 51, 18	1, 10, 40	0, 40, 38	
14,400	41.99	41.98	58.77	58.76	32.62	50.50	3, 44, 0	5, 46, 0	1, 38, 30	0, 57, 10	0, 41, 20	
18,000	28.56	28.56	51.40	51.40	19.20	43.14	2, 12, 0	4, 55, 50	1, 32, 0	0, 50, 10	0, 41, 50	
18,000	89.61	89.61	81.38	81.39	80.25	73.12	9, 7, 10	8, 19, 10	.....	.....	.....	
19,800	83.01	83.01	78.13	78.14	73.65	69.87	8, 22, 50	7, 57, 20	0, 44, 20	0, 21, 50	0, 23, 30	
21,600	74.16	74.15	74.60	74.60	64.80	66.34	7, 23, 0	7, 33, 30	0, 59, 50	0, 23, 50	0, 36, 0	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.46″
Length of specimen between jaws	77.5″
Dimension of cross section	2 in. dia.
Length of specimen between telescopes	60.00″
Elastic limit in torsion	19,800 in. lbs.
Maximum twisting moment	79,650 in. lbs.
Number of turns of specimen between jaws at fracture	19.1
Outside fiber stress at elastic limit	12,600 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	50,700 lbs. per sq. in.
Angle of twist between 3,600 in. lbs. and 18,000 in. lbs.	2° 44′ 20″
Shearing modulus of elasticity between 3,600 in. lbs. and 18,000 in. lbs.	11,400,000
Average number of turns of specimen per foot at fracture	2.96

TORSION TEST.

Specimen, Swedish Iron. Date, December 2, 1895.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.	Remarks.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.		
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
3,600	89.57	89.58	86.04	86.04	80.21	77.78	9, 6, 50	8, 50, 30	.. ..	.. ..	.. ..	
7,200	73.42	73.43	75.90	75.90	64.06	67.64	7, 21, 40	7, 42, 20	1, 45, 10	1, 8, 10	0, 37, 0	At 23,400 in. lbs. load the scale beam dropped.
10,800	57.80	57.79	66.20	66.20	48.43	57.94	5, 32, 0	6, 36, 40	1, 49, 40	1, 5, 40	0, 44, 0	
14,400	42.90	42.90	57.20	57.19	33.54	48.93	3, 50, 20	5, 35, 20	1, 41, 40	1, 1, 20	0, 40, 20	
18,000	30.03	30.04	50.30	50.30	20.67	42.04	2, 22, 0	4, 48, 20	1, 28, 20	0, 47, 0	0, 41, 20	
18,000	92.58	92.59	82.93	82.92	83.22	74.66	9, 27, 0	8, 29, 40	.....	.....	.. ..	Specimen fractured at power end jaw.
19,800	87.00	87.01	80.49	80.48	77.65	72.22	8, 49, 40	8, 13, 10	0, 37, 20	0, 16, 30	0, 20, 50	
21,600	80.56	80.57	77.69	77.70	71.20	69.43	8, 6, 20	7, 54, 20	0, 43, 20	0, 18, 50	0, 24, 30	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale . . . . . power end, 3.90: scale end, 2.80″	
Height of center of telescope above center of test piece	5.46″
Length of specimen between jaws	76.75″
Dimension of cross section	2.01 in. dia.
Length of specimen between telescopes	60.00″
Elastic limit in torsion	19,800 in. lbs.
Maximum twisting moment	82,530 in. lbs.
Number of turns of specimen between jaws at fracture	24.3
Outside fiber stress at elastic limit	12,600 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	52,500 lbs. per sq. in.
Angle of twist between 7,200 in. lbs. and 14,400 in. lbs.	1° 24′ 20″
Shearing modulus of elasticity between 7,200 in. lbs. and 14,400 in. lbs.	11,200,000
Average number of turns of specimen per foot at fracture	3.80

TORSION TEST.

Specimen, Swedish Iron. Date, December 5, 1895.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.	Remarks.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.		
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
10,800	58.80	58.80	65.47	65.49	49.44	57.22	5, 38, 50	6, 31, 40	.. ..	.. ..	.. ..	
14,400	44.20	44.19	56.72	56.73	34.83	48.46	3, 59, 10	5, 32, 10	1, 39, 40	0, 59, 30	0, 40, 10	At 25,200 in. lbs. load the scale beam dropped.
16,200	37.82	37.82	53.11	53.11	28.48	44.85	3, 15, 20	5, 7, 30	0, 43, 50	0, 24, 40	0, 19, 10	
18,000	31.50	31.52	49.78	49.80	22.15	41.53	2, 32, 10	4, 44, 50	0, 43, 10	0, 22, 40	0, 20, 30	
18,000	91.93	91.92	88.01	88.01	82.56	79.75	9, 22, 40	9, 3, 40	.....	.....	.. ..	
19,800	86.03	86.01	85.09	85.07	76.66	76.82	8, 43, 0	8, 44, 0	0, 39, 40	0, 19, 40	0, 20, 0	Specimen fractured at power end jaw.
21,600	80.00	80.00	82.03	82.04	70.64	73.77	8, 2, 30	8, 23, 10	0, 40, 30	0, 20, 50	0, 19, 40	
23,400	74.09	74.10	79.22	79.22	64.73	70.96	7, 22, 40	8, 4, 40	0, 39, 50	0, 18, 30	0, 21, 20	
25,200	.....	.....	....	.....	.....	.....	.....	.....	.....	.....	.. ..	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale . . . . . power end, 3.90; scale end, 28.0″	
Height of center of telescope above center of test piece	5.46″
Length of specimen between jaws	80.5″
Dimension of cross section	2.00 in. dia.
Length of specimen between telescopes	60.00″
Elastic limit in torsion	23,400 in. lbs.
Maximum twisting moment	84,330 in. lbs.
Number of turns of specimen between jaws at fracture	22.3
Outside fiber stress at elastic limit	14,900 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	53,700 lbs. per sq. in.
Angle of twist between 10,800 in. lbs. and 19,800 in. lbs.	1° 39′ 50″
Shearing modulus of elasticity between 10,800 in. lbs. and 19,800 in. lbs.	11,700,000
Average number of turns of specimen per foot at fracture	3.32

TORSION TEST.

Specimen, Swedish Iron. Date, December 10, 1895.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.	
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″
1,800	88.62	88.60	86.06	86.07	79.25	77.80	9, 0, 20	8, 50, 40	.. .. ..	.. .. ..	.. .. ..
3,600	74.60	74.60	75.07	75.07	65.24	66.81	7, 26, 0	7, 36, 40	1, 34, 20	1, 14, 0	0, 20, 20
5,400	62.92	62.92	66.34	66.34	53.56	58.08	6, 6, 50	6, 37, 30	1, 19, 10	0, 59, 10	0, 20, 0
7,200	53.20	53.22	59.59	59.58	43.85	51.32	5, 0, 40	5, 51, 40	1, 6, 10	0, 45, 50	0, 20, 20
9,000	45.27	45.27	54.68	54.68	36.11	46.42	4, 8, 10	5, 18, 10	0, 52, 30	0, 33, 30	0, 19, 0
10,800	38.10	38.10	50.40	50.40	28.74	42.14	3, 17, 20	4, 49, 0	0, 50, 50	0, 29, 10	0, 21, 40
12,600	31.03	31.05	46.26	46.26	21.68	38.00	2, 29, 0	4, 21, 10	0, 48, 20	0, 27, 50	0, 20, 30
12,600	90.13	90.12	90.40	90.40	80.76	82.14	9, 10, 30	9, 19, 50	.. .. ..	.. .. ..	.. .. ..
14,400	85.57	85.57	88.77	88.77	76.21	80.51	8, 40, 0	9, 8, 50	0, 30, 30	0, 11, 0	0, 19, 30
16,200	79.47	79.47	85.66	85.65	70.11	77.40	7, 59, 0	8, 48, 0	0, 41, 0	0, 20, 50	0, 20, 10
18,000	73.20	73.22	82.41	82.40	63.85	74.14	7, 16, 40	8, 26, 0	0, 42, 20	0, 22, 0	0, 20, 20
19,800	67.01	67.01	79.18	79.17	57.65	70.91	6, 34, 40	8, 4, 20	0, 42, 0	0, 21, 40	0, 20, 20
	Piece rested for two hours.										
19,800	72.88	72.88	79.90	79.88	63.52	71.63	7, 14, 20	8, 09, 10	.. .. ..	.. .. ..	.. .. ..
21,600	67.30	67.32	77.26	77.25	57.95	69.00	6, 36, 40	7, 52, 30	0, 38, 40	0, 21, 00	.. .. ..
23,400	60.98	61.00	74.12	74.10	51.63	65.85	5, 53, 40	7, 30, 10	0, 43, 00	0, 20, 40	.. .. ..
25,200	Piece would not hold load.										

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.46″
Length of specimen between jaws	75.00″
Dimension of cross section	2.00 in. dia.
Length of specimen between telescopes	60.00″
Elastic limit in torsion	23,400 in. lbs.
Maximum twisting moment	84,960 in. lbs.
Number of turns of specimen between jaws at fracture	18.1
Outside fiber stress at elastic limit	14,900 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	54,100 lbs. per sq. in.
Angle of twist between 1,800 in. lbs. and 7,200 in. lbs.	1° 0′ 40″
Shearing modulus of elasticity between 1,800 in. lbs. and 7,200 in. lbs.	11,700,000
Average number of turns of specimen per foot at fracture	2.90

TORSION TEST.

Specimen, Bessemer Steel. Date, December 16, 1895.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.	Remarks.
	Power end		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.		
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
1,800	92.58	92.58	90.10	90.10	83.58	82.20	9, 29, 20	9, 20, 10	.....	.....	.....	
5,400	60.68	60.67	70.73	70.71	51.68	62.82	5, 54, 0	7, 9, 40	3, 35, 20	2, 10, 30	1, 24, 50	At 19,800 in. lbs. load the scale beam dropped.
5,400	88.32	88.30	84.69	84.69	79.31	76.79	9, 0, 50	8, 43, 50	.....	.....	.....	
9,000	60.97	60.97	69.83	69.83	51.97	61.93	5, 56, 0	7, 3, 40	3, 4, 50	1, 40, 10	1, 24, 40	
9,000	88.01	88.01	84.60	84.59	79.01	76.70	8, 58, 50	8, 43, 20	.....	.....	.....	Specimen fractured at power end jaw.
12,600	61.20	61.19	70.25	70.27	52.20	62.36	5, 57, 40	7, 6, 30	3, 01, 10	1, 36, 50	1, 24, 20	
12,600	89.13	89.15	83.77	83.76	80.14	75.87	9, 13, 0	8, 37, 40	.....	.....	.....	
16,200	63.68	63.70	70.87	70.87	54.69	62.97	6, 14, 50	7, 10, 40	2, 58, 10	1, 27, 0	1, 31, 10	
16,200	88.62	88.64	85.90	85.90	79.63	78.00	9, 3, 0	8, 52, 6	.....	.....	.....	
18,000	76.37	76.39	79.96	79.95	67.38	72.06	7, 40, 30	8, 12, 0	1, 22, 30	0, 40, 0	0, 42, 30	
19,800	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale . . . . . power end, 3.90; scale end, 2.80″	
Height of center of telescope above center of test piece	5.10″
Length of specimen between jaws	58.8″
Dimension of cross section	1.50 in. dia.
Length of specimen between telescopes	40.00″
Elastic limit in torsion	18,000 in. lbs.
Maximum twisting moment	44,460 in. lbs.
Number of turns of specimen between jaws at fracture	10.5
Outside fiber stress at elastic limit	27,200 lbs. per. sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	67,100 lbs. per. sq. in.
Angle of twist between 1,800 in. lbs. and 9,000 in. lbs.	2° 49′ 30″
Shearing modulus of elasticity between 1,800 in. lbs. and 9,000 in. lbs.	11,700,000
Average number of turns of specimen per foot at fracture	2.14

TORSION TEST.

Specimen, Bessemer Steel. Date, March 5, 1896.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.	Remarks.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.		
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
1,800	92.22	92.23	86.88	86.89	83.22	78.98	9,27, 0	8, 58, 30	.. ..	... .	.. ..	
5,400	54.89	54.89	62.30	62.30	45.89	54.40	5, 14, 40	6, 12, 30	4, 12, 20	2, 46, 0	1, 26, 20	At 18,000 in. lbs. load the
5,400	94.23	94.22	81.39	81.40	85.22	73.49	9, 40, 20	8, 21, 40	.. ..	... .	.. ..	scale beam dropped.
9,000	57.10	57.10	57.10	57.10	48.10	49.20	5, 29, 40	5, 37, 10	4, 10, 40	2, 44, 30	1, 26, 10	
9,000	89.95	89.94	78.82	78.82	80.94	70.02	9, 11, 40	8, 4, 20	....	... .	.. ..	
12,600	58.10	58.10	59.74	59.72	49.10	51.83	5, 36, 30	5, 55, 10	3, 35, 10	2, 9, 10	1, 26, 0	
12,600	93.80	93.80	84.90	84.89	84.80	76.99	9, 37, 30	8, 45, 10	.. ..	... .	.. ..	
16,200	65.59	65.59	69.40	69.39	56.59	61.49	6, 27, 30	7, 0, 40	3, 10, 0	14, 4, 30	1, 25, 30	
16,200	93.60	93.60	88.94	88.94	84.60	80.04	9, 36, 10	9, 8, 10	....	....	.. ..	
18,000	.....	.....	.....	.....	.....	.....	.. ..	....	.. ..	....	.. ..	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.10″
Length of specimen between jaws	59.1″
Dimension of cross section	1.50 in. dia.
Length of specimen between telescopes	40.00″
Elastic limit in torsion	16,200 in. lbs.
Maximum twisting moment	45,000 in. lbs.
Number of turns of specimen between jaws at fracture	13.2
Outside fiber stress at elastic limit	24,400 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	67,900 lbs. per sq. in.
Angle of twist between 1,800 in. lbs. and 12,600 in. lbs.	4° 18′ 30″
Shearing modulus of elasticity between 1,800 in. lbs. and 12,600 in. lbs.	11,500,000
Average number of turns of specimen per foot at fracture	2.68

TORSION TEST.

Specimen, Bessemer Steel. Date, March 10, 1896.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.	Remarks.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.		
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
1,800	91.34	91.36	88.88	88.86	82.35	80.97	9, 21, 10	9, 12, 0	.. ..	....	.. ..	
5,400	54.94	54.93	65.01	65.02	45.93	87.11	5, 15, 0	6, 31, 0	4, 6, 10	2, 41, 0	1 ,25, 10	At 19,800 in. lbs. load the
5,400	81.42	81.42	81.85	81.85	72.42	73.95	8, 14, 30	8, 24, 50	....	... .	.. ..	scale beam dropped.
9,000	51.83	51.85	64.68	64.66	42.84	56.77	4, 53, 50	6, 28, 40	3, 20, 40	1, 56, 10	1, 24, 20	
9,000	85.60	85.62	80.30	80.28	76.61	72.39	8, 42, 40	8, 14, 20	.. ..	... .	.. ..	Specimen fractured at
12,600	58.29	58.30	65.54	65.54	49.29	57.64	5, 37, 50	6, 34, 30	3, 4, 50	1, 39, 50	1, 25, 0	power end jaw.
12,600	87.30	87.28	83.21	83.20	78.29	75.30	8, 54, 0	8, 32, 50	....	... .	.. ..	
14,400	75.00	75.00	77.20	77.20	66.00	69.30	7, 31, 10	7, 53, 30	1, 22, 50	0, 40, 20	0, 42, 30	
16,200	62.40	62.41	70.98	70.96	53.40	63.07	6, 5, 50	7, 11, 20	1, 25, 20	0, 42, 10	0, 43, 10	
18,000	49.69	49.69	64.50	64.50	40.69	56.60	4, 39, 10	6, 27, 30	1, 26, 40	0, 43, 50	0, 42, 50	
19,800	.....	.....	.....	.....	.....	.....	.. ..	....	.. ..	....	.. ..	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.10″
Length of specimen between jaws	58.25″
Dimension of cross section	1.5 in. dia.
Length of specimen between telescopes	40.0″
Elastic limit in torsion	18,000 in. lbs.
Maximum twisting moment	44,920 in. lbs.
Number of turns of specimen between jaws at fracture	10.8
Outside fiber stress at elastic limit	27,200 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	67,800 lbs. per sq. in.
Angle of twist between 1,800 in. lbs. and 12,600 in. lbs.	4° 14′ 40″
Shearing modulus of elasticity between 1,800 in. lbs. and 12,600 in. lbs.	11,700,000
Average number of turns of specimen per foot at fracture	2.22

TORSION TEST.

Specimen, Composition. Date, March, 19, 1896.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.	Remarks.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.		
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
900	91.63	91.63	85.70	85.70	82.63	77.80	9, 23, 0	8, 50, 40	.. ..	.....	.. ..	85% copper, 7% spelter, 8% tin.
1,800	84.56	84.57	82.23	82.23	75.56	74.35	8, 35, 40	8, 27, 20	0, 47, 20	0, 23, 20	0, 24, 0	
2,700	78.63	78.64	79.88	79.88	69.64	71.98	7, 55, 40	8, 11, 30	0, 40, 0	0, 15, 50	0, 24, 10	At 6,300 in. lbs. load the scale beam dropped.
3,600	70.90	70.92	76.00	76.00	61.91	68.10	7, 3, 40	7, 45, 20	0, 52, 0	0, 26, 10	0, 25, 50	
4,500	61.20	61.20	71.11	71.12	52.20	63.22	5, 57, 40	7, 12, 20	1, 6, 0	0, 33, 0	0, 33, 0	
5,400	46.20	46.18	65.50	65.50	37.19	57.60	4, 15, 10	6, 34, 20	1, 42, 30	0, 38, 0	1, 4, 30	Fractured 8″ from power end jaw.
6,300	.....	.....	.....	.....	.....	.....	.. .. ..	.. ..	.. ..	.. ..	.. ..	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.10″
Length of specimen between jaws	28.0″
Dimension of cross section	1.52 in. dia.
Length of specimen between telescopes	20.00″
Elastic limit in torsion	4,500 in. lbs.
Maximum twisting moment	23,130 in. lbs.
Number of turns of specimen between jaws at fracture	3.6
Outside fiber stress at elastic limit	6,530 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	33,500 lbs. per sq. in
Angle of twist between 900 in. lbs. and 2,700 in lbs.	0° 48′ 10″
Shearing modulus of elasticity between 900 in. lbs. and 2,700 in. lbs.	4,810,000
Average number of turns of specimen per foot at fracture	1.54

TORSION TEST.

Specimen, Composition. Date, March 23, 1896.

Twisting moment.	Scale Readings.				Corrected Mean.		Angles Corresponding.		Differences.		Angle of twist.	Remarks.
	Power end.		Scale end.		Power end.	Scale end.	Power end.	Scale end.	Power end.	Scale end.		
	1	2	1	2			° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
720	92.90	92.90	93.00	92.98	83.90	85.09	9, 31, 30	9, 39, 30	.. ..	.. ..	.. ..	85% copper, 7% spelter, 8% tin.
1,440	85.68	85.70	88.55	88.55	76.60	80.65	8, 43, 10	9, 9, 50	0, 48, 20	0, 29, 40	0, 18, 40	
2,160	74.40	74.40	80.05	80.05	65.40	72.15	7, 27, 10	8, 12, 40	1, 16, 0	0, 57, 10	0, 18, 50	
2,880	65.60	65.60	73.95	73.96	56.61	66.06	6, 30, 0	7, 31, 30	0, 57, 10	0, 41, 10	0, 16, 0	At 6,480 in. lbs. load the scale beam dropped.
3,600	56.88	56.90	68.10	68.09	47.89	60.19	5, 28, 20	6, 51, 50	1, 1, 40	0, 39, 40	0, 22, 0	
4,320	49.42	49.43	63.68	63.67	40.42	55.77	4, 37, 20	6, 21, 50	0, 51, 0	0, 30, 0	0, 21, 0	
5,040	41.70	41.70	59.59	59.57	32.70	51.68	3, 44, 30	5, 54, 0	0, 52, 50	0, 27, 50	0, 25, 0	Specimen fractured at power end jaw.
5,760	31.64	31.64	55.00	55.01	22.64	47.10	2, 35, 30	5, 22, 50	1, 9, 0	0, 31, 10	0, 37, 50	
5,760	92.09	92.08	89.94	89.92	.....	.....	.. ..	.. ..	.. .. ..	.. ..	.. ..	
6,480	.....	.....	.....	.....	.....	.....	.. ..	.. ... .	.. ..	.. ..	.. ..	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of telescope above center of test piece	5.10″
Length of specimen between jaws	27.00″
Dimension of cross section	1.51 in. dia.
Length of specimen between telescopes	20.00″
Elastic limit in torsion	5,040 in. lbs.
Maximum twisting moment	28,800 in. lbs.
Number of turns of specimen between jaws at fracture	5.0
Outside fiber stress at elastic limit	7,460 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	42,600 lbs. per sq. in.
Angle of twist between 720 in. lbs. and 2,160 in. lbs.	0° 37′ 30″
Shearing modulus of elasticity between 720 in. lbs and 2,160 in. lbs.	5,210,000
Average number of turns of specimen per foot at fracture	2.22

TORSION TEST.

Specimen, Brass. Date, March 25, 1896.

Twisting moment.	Scale Readings. Power end. 1	2	Scale end. 1	2	Corrected Mean. Power end.	Scale end.	Angles Corresponding. Power end. ° ′ ″	Scale end. ° ′ ″	Differences. Power end. ° ′ ″	Scale end. ° ′ ″	Angle of twist. ° ′ ″	Remarks.
720	91.03	91.03	88.33	88.31	82.03	80.42	9, 19, 0	9, 8, 10	.....	.....	.. ..	
1,440	77.89	77.91	78.12	78.11	68.90	70.22	7, 50, 40	8, 0, 20	1, 28, 20	1, 7, 50	0, 20, 30	65% copper,
2,160	64.35	64.33	67.62	67.62	55.34	59.70	6, 19, 0	6, 48, 30	1, 31, 40	1, 11, 50	0, 19, 50	35% spelter.
2,520	57.20	57.20	62.26	62.28	48.20	54.37	5, 30, 20	6, 12, 20	0, 48, 40	0, 36, 10	0, 12, 30	
2,880	50.46	50.48	57.70	57.70	41.47	49.80	4, 44, 30	5, 41, 20	0, 45, 50	0, 31, 0	0, 14, 50	Specimen fractured at
3,240	42.65	42.66	52.55	52.57	33.66	44.66	3, 51, 0	5, 6, 10	0, 53, 30	0, 35, 10	0, 18, 20	center.
3,600	32.81	32.80	46.40	46.39	23.81	38.50	2, 43, 35	4, 24, 10	1, 7, 25	0, 42, 0	0, 25, 25	
3,960	91.52	91.51	88.71	88.70	82.52	78.80	9, 22, 25	9, 10, 50	.....	.....	.. ..	
4,320	69.15	69.13	81.10	81.16	60.14	73.20	6, 31, 30	8, 19, 20	2, 50, 55	0, 49, 30	2, 1, 25	
4,680	26.73	26.75	68.75	68.77	17.74	61.80	2, 2, 0	7, 2, 40	4, 29, 30	1, 16, 40	3, 12, 50	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.10″
Length of specimen between jaws	28.00″
Dimension of cross section	1.51 in. dia.
Length of specimen between telescopes	20.00″
Elastic limit in torsion	3,600 in. lbs.
Maximum twisting moment	17,460 in. lbs.
Number of turns of specimen between jaws at fracture	3.5
Outside fiber stress at elastic limit	5,220 lbs. per sq in.
Apparent outside fiber stress as calculated from maximum twisting moment	25,900 lbs. per sq. in.
Angle of twist between 720 in. lbs. and 2,520 in. lbs.	0° 52′ 50″
Shearing modulus of elasticity between 720 in. lbs. and 2,520 in. lbs.	4,380,000
Average number of turns of specimen per foot at fracture	1.50

TORSION TEST.

Specimen, Bessemer Steel. Date, March 26, 1896.

Twisting moment.	Scale Readings. Power end. 1	2	Scale end. 1	2	Corrected Mean. Power end.	Scale end.	Angles Corresponding. Power end. ° ′ ″	Scale end. ° ′ ″	Differences. Power end. ° ′ ″	Scale end. ° ′ ″	Angle of twist. ° ′ ″	Remarks.
1,800	91.85	91.85	78.45	78.44	82.85	70.54	9, 24, 20	8, 1, 50	.. ..	.. ..	.. ..	
3,600	73.10	73.10	65.90	65.91	64.10	65.90	7, 18, 20	6, 39, 40	2, 6, 0	1, 22, 10	0, 43, 50	At 19,800 in. lbs. load the
5,400	57.34	57.36	56.62	56.62	48.35	48.72	5, 31, 20	5, 34, 0	1, 47, 0	1, 5, 40	0, 41, 20	scale beam dropped.
7,200	42.76	42.77	48.22	48 22	33.76	40.32	3, 51, 45	4, 36, 40	1, 39, 35	0, 57, 20	0, 42, 15	
9,000	27.98	27.99	39.60	39.60	18.98	31.70	2, 10, 30	3, 37, 40	1, 41, 15	0, 59, 0	0, 40, 15	Specimen fractured at
9,000	93.78	93.80	90.00	89.98	84.79	82.09	9, 37, 30	9, 19, 30	.. ..	.....	.. ..	power end jaw.
10,800	77.55	77.56	81 80	81.80	68.55	73.90	7, 48, 30	8, 24, 25	1, 49, 0	0, 55, 5	0, 53, 55	
10,800	94.10	94.08	87.30	87.30	85.09	79.40	9, 39, 30	9, 1, 40	.....	.....	.. .. ..	
12,600	80.36	80.36	79.80	79.79	71.36	71.69	8, 7, 20	8, 12, 30	1, 32, 10	0, 49, 10	0, 43, 0	
14,400	66.90	66.92	72.60	72.60	57.91	64.70	6, 36, 20	7, 22, 20	1, 31, 0	0, 50, 10	0, 40, 50	
16,200	53.78	53.78	65.72	65.70	44.78	57.81	5, 7, 0	6, 35, 40	1, 29, 20	0, 46, 40	0, 42, 40	
18,000	41.58	41.60	59.67	59.66	32.59	51.76	3, 43, 40	5, 54, 40	1, 23, 20	0, 41, 0	0, 42, 20	
19,800	.....	.....	.....	.....	.....	.....	.. ..	.. ..	.. ..	.. ..	.. ..	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.10″
Length of specimen between jaws	58.0″
Dimension of cross section	1.50 in. dia.
Length of specimen between telescopes	40.00″
Elastic limit in torsion	18,000 in. lbs.
Maximum twisting moment	45,540 in. lbs.
Number of turns of specimen between jaws at fracture	11.4
Outside fiber stress at elastic limit	27,200 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	68,700 lbs. per sq. in.
Angle of twist between 1,800 in. lbs. and 9,000 in. lbs.	2° 49′ 40″
Shearing modulus of elasticity between 1,800 in. lbs. and 9,000 in. lbs.	11,700,000
Average number of turns of specimen per foot at fracture	2.36

TORSION TEST.

Specimen, Swedish Iron Bar. Date, March 27, 1896.

Twisting moment.	Scale Readings. Power end. 1	2	Scale end. 1	2	Corrected Mean. Power end.	Scale end.	Angles Corresponding. Power end. ° ′ ″	Scale end. ° ′ ″	Differences. Power end. ° ′ ″	Scale end. ° ′ ″	Angle of twist. ° ′ ″	Remarks.
3,600	93.46	93.46	91.11	91.11	84.10	82.85	9, 32, 50	9, 24, 30	....	....	.. ..	
7,200	72.10	72.10	75.69	75.69	62.74	67.43	7, 9, 10	7, 40, 50	2, 23, 4	1, 43, 40	0, 40, 0	At 25,200 in. lbs. load the scale beam dropped.
10,800	54.10	54.10	63.60	63.60	44.74	55.34	5, 6, 50	6, 19, 0	2, 2, 20	1, 21, 50	0, 40, 30	
14,400	40.40	40.40	55.69	55.68	31.04	47.42	3, 33, 10	5, 25, 0	1, 33, 40	0, 54, 0	0, 39, 40	
18,000	28.11	28.11	49.14	49.17	18.75	40.88	2, 8, 50	4, 40, 30	1, 24, 20	0, 44, 30	0, 39, 50	Specimen fractured at power end jaw.
18,000	94.00	94.00	88.84	88.85	84.64	80.59	9, 36, 30	9, 9, 20	....	....	....	
19,800	97.60	87.60	85.45	85.45	78.24	77.19	8, 53, 40	8, 46, 30	0, 42, 50	0, 22, 50	0, 20, 0	
21,600	81.60	81.60	82.45	82.45	72.24	74.19	8, 13, 20	8, 26, 20	0, 40, 20	0, 20, 10	0, 20, 10	
23,400	75.88	75.88	79.78	79.78	56.52	71.52	7, 34, 20	8, 8, 30	0, 39, 0	0, 17, 50	0, 21, 50	
25,200	.....	.....	.....	.....	.....	.....	.. ..	.. ..	.. .. ..	.. ..	.. ..	

Distance from center of test piece to scale	500.0″
Reading of level of center of test piece on scale	power end, 3.90; scale end, 2.80″
Height of center of telescope above center of test piece	5.46″
Length of specimen between jaws	79.00″
Dimension of cross section	2.02 in. dia.
Length of specimen between telescopes	60.00″
Elastic limit in torsion	23,400 in. lbs.
Maximum twisting moment	82,350 in. lbs.
Number of turns of specimen between jaws at fracture	21.0
Outside fiber stress at elastic limit	14,300 lbs. per sq. in.
Apparent outside fiber stress as calculated from maximum twisting moment	50,400 lbs. per sq. in.
Angle of twist between 36,000 in. lbs. and 18,000 in. lbs.	2° 40′ 0″
Shearing modulus of elasticity between 36,000 in. lbs. and 18,000 in. lbs.	11,300,000
Average number of turns of specimen per foot at fracture	3.19

Rope Tests.

ROPE TESTS.

Date.	Specimen.	Size. Circumference. (Inches.)	Number of strands.	Feet per pound.	Turns per foot.	Method of holding.
1895.						
Oct. 21	Manila.	3	3	2.26	4.2	Eye splices.
Oct. 21	Manila.	4	3	1.57	3 0	Eye splices.
Oct. 23	Manila.	3	3	2 83	5.3	Eye splices and bowline.
Oct. 25	Manila.	3	3	2.38	4.0	Eye splices.
Oct. 28	Manila.	3	3	2.50	4.0	Eye splices. (Not tapered.)
Oct. 28	Manila.	4	3	2.90	4.0	Eye splices. (Not tapered.)
Oct. 30	American hemp. (Dry.)	3½	3	1.90	7.0	Eye splices.
Nov. 1	American hemp. (Dry.)	3	3	....	5.0	Eye splices.
Nov. 4	Russian hemp. (Dry.)	2½	3	....	5 7	Eye splices.
Nov. 6	Russian hemp. (Tarred.)	2½	3	3.67	5.5	Eye splices.
Nov. 6	Sisal.	3	3	2.90	4.5	Eye splices.
Nov. 8	American hemp. (Dry.)	2½	3	6.30	6.0	Eye splices.
Nov. 11	Cotton.	2	3	11.62	9.0	Eye splices.
Nov. 13	Cotton.	2	3	11.43	9.0	Eye splices.
Nov. 14	Manila.	7	3	1.00	2.0	Eye splices.
Nov. 15	Manila.	7	3	.75	2.0	Eye splices.
Nov. 18	Cotton.	2	3	10.00	9.0	Eye splices.
Nov. 19	American hemp. (Dry.)	2½	3	18.00	6.0	Eye splices.
Nov. 20	Russian hemp. (Dry.)	3	3	....	5.5	Eye splices.
Nov. 20	Russian hemp. (Tarred.)	3	3	....	6.0	Eye splices.
Nov. 22	Russian hemp. (Dry.)	2½	3	5.00	5.7	Eye splices.
Nov. 22	Russian hemp. (Tarred.)	2½	3	4.30	6.0	Eye splices.
Nov. 25	American hemp. (Dry.)	2½	3	5.75	5.3	Eye splices.
Nov. 25	American hemp. (Tarred.)	2½	3	4.38	5.0	Eye splices.
Nov. 27	Sisal.	3	3	3 60	4.5	Eye splices.
Dec. 2	Sisal.	3	3	3.64	5 0	Eye splices.
Dec. 2	Sisal.	3	3	3.70	5.0	Eye splices.
Dec. 4	Cotton.	2	3	11.40	8.7	Eye splices.
Dec. 6	American hemp. (Dry.)	2½	3	5.83	18.0	Eye splices.
Dec. 6	American hemp. (Tarred.)	2½	3	5.00	5.0	Eye splices.
Dec. 9	American hemp. (Dry.)	3	3	3.92	15.0	Eye splices.
1896.						
Mar. 4	American hemp. (Dry.)	2½	3	5.77	6.0	Eye splices.
Mar. 5	Cotton.	2	3	11.50	9.0	Eye splices.
Mar. 5	Manila.	2½	3	5.33	5.3	Eye splices.
Mar. 6	Cotton.	2	3	11.56	9.0	Eye splices.
Mar. 10	Russian hemp. (Tarred.)	2½	3	....	5.5	Eye splices.
Mar. 10	Manila.	2½	3	5.20	5.5	Eye splices.
Mar. 10	American hemp. (Dry.)	2½	3	3.68	5.0	Eye splices.
Mar. 11	Sisal.	3	3	3.70	5.0	Eye splices.
Mar. 23	Manila.	3	3	3.91	4.0	Eye splices.
Mar. 25	Manila.	3	3	5.00	4.0	Eye splices.
Mar. 26	Manila.	3	3	4.00	4.2	Eye splices.
Mar. 30	Manila.	3	3	4.70	4.3	Eye splices.
Mar. 30	Manila.	3	3	4.70	4.3	Eye splices.
Mar. 31	Manila.	3	3	5.00	4.0	Eye splices.
April 1	Manila.	3	3	5.00	4.1	Eye splices.

ROPE TESTS. — *Continued.*

Condition.	Location of break.	Breaking load. (Lbs.)	Remarks.
Dry. Wet splices.	Center.	8,996	
Dry.	Splice.	10,136	
Dry. Wet splices.	Bowline.	3,480	
Dry. Wet splices.	Center.	9,574	
Dry. Wet splices.	Center.	5,829	One strand slightly damaged before test.
Dry. Wet splices.	Splice.	8,031	
Dry. Wet splices.	Lower splice.	7,220	
Dry. Wet splices.	Lower splice.	7,354	
Dry. Wet splices.	Center.	7,021	
Dry. Wet splices.	Center.	5,252	
Dry. Wet splices.	Lower splice.	6,214	
Dry. Wet splices.	Center.	5,980	
Dry. Wet splices.	Center.	1,789	
Dry. Wet splices.	Center.	1,986	
Dry.	Upper splice.	22,394	
Dry. Wet splices.	Center.	24,551	
Dry. Wet splices.	Center.	1,870	
Dry. Wet splices.	Splice.	4,749	
Dry. Wet splices.	Splice.	7,206	
Dry. Wet splices.	Lower splice.	5,074	
Dry. Wet splices.	Upper splice.	6,876	
Dry. Wet splices.	Center.	4,697	
Dry. Wet splices.	Upper splice.	4,098	
Dry. Wet splices.	Upper splice.	4,231	
Dry. Wet splices.	Upper splice.	5,637	
Dry.	Lower splice.	4,400	
Dry.	Lower splice.	6,465	
Dry. Wet splices.	Center.	1,508	
Dry. Wet splices.	Upper splice.	4,648	
Dry. Wet splices.	Upper splice.	5,620	
Dry. Wet splices.	Lower splice.	6,831	
Dry. Wet splices.	Lower splice.	3,922	
Dry. Wet splices.	No break.	.....	Maximum load = 1,831 lbs. Specimen stretched beyond limit of machine.
Dry.	Splice.	4,712	
Dry. Wet splices.	Center.	1,776	
Dry. Wet splices.	Center.	5,786	
Dry. Wet splices.	Center.	5,295	
Dry. Wet splices.	Upper splice.	7,267	Uninjured ends of two broken specimens joined by square knot.
Dry.	Knot.	3,560	Left handed overhand knot at center.
Dry. Wet splices.	Knot.	4,439	Right handed overhand knot at center.
Dry. Wet splices.	Knot.	4,739	
Dry. Wet splices.	Knot.	4,044	Figure eight knot at center.
Dry. Wet splices.	Knot.	6,320	Ordinary overhand tie at center.
Dry. Wet splices.	Knot.	3,780	Open hand knot at center.
Dry. Wet splices.	Knot.	5,386	Shroud knot at center.
Dry. Wet splices.	Knot.	5,169	Weaver's knot at center.

INVESTIGATION TO DETERMINE WHETHER DIPHENYLIODONIUM AND THALLIUM NITRATES ARE ISOMORPHOUS.

By A. A. NOYES, Ph.D., and C. W. HAPGOOD, S.B.

Received June 15, 1896.

The great similarity in properties observed by V. Meyer[1] between the salts of thallium and diphenyliodonium, $(C_6H_5)_2I\text{-}OH$, made it seem not improbable that they might be also isomorphous with each other. The matter seemed worthy of investigation, as only a few such cases of isomorphous replacement of single atoms by complex organic radicals are known.

According to the extended investigations of Retgers, by far the most reliable criterion of isomorphism is furnished by the power of the substances in question of forming homogeneous mixed crystals with the proportions varying continuously within wide limits. Consequently, the experimental method based on this principle as described by Retgers[2] was followed, chemical analysis and specific gravity determinations being employed to determine the character of the crystals separating from the solution. Preliminary experiments showed that the largest and most perfect crystals were obtained with the nitrates when crystallized from alkaline solution. Saturated solutions of thallous nitrate in water and of diphenyliodonium nitrate[3] in a moderately strong aqueous solution of the free base, diphenyliodonium hydrate, were therefore prepared, mixed with each other in crystallizing dishes in varying proportions, and allowed to stand in a vacuum desiccator till a sufficient quantity of crystals had separated. The solutions were mixed in the following proportions, the number of parts of the diphenyliodonium nitrate solution being given

[1] Berichte der deutschen chemischen Gesellschaft, 27, 502, 1592.

[2] Zeitschrift für physikalische Chemie, 4, 593.

[3] Made as described by Hartmann and V. Meyer, Berichte der deutschen chemischen Gesellschaft, 27, 506.

first: 10:1.1; 10:2; 10:5; 10:6.7; 10:10; 10:15; 10:20; 10:50; and 10:90.

The first crop from the last solutions consisted of two distinct kinds of crystals, one kind much lighter and the other much heavier than methylene iodide. In all the other cases only one kind of crystals, which were lighter than methylene iodide, was obtained. The specific gravity of these lighter crystals separating from each of the nine solutions was determined by the suspension method of Retgers,[1] the value taken being that corresponding to the heaviest crystals of each lot. The results varied irregularly between 1.866 and 1.889. For the pure diphenyliodonium nitrate we found 1.868. For thallous nitrate Lamy[2] found 5.8. The lighter crystals were therefore in all nine cases practically pure diphenyliodonium nitrate. The heavier crystals from the last solutions were mixed together, dried at 100°, and analyzed by heating in a crucible with concentrated sulphuric acid and igniting. Two separate determinations showed them to contain 99.83 and 99.93 per cent. of thallous nitrate.

Thus the two salts crystallize out separately from the solution in the pure state, not in the form of mixed crystals. They are therefore not isomorphous.

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[1] Zeitschrift für physikalische Chemie, 3, 289.

[2] Annales de chimie et de physique (3), 67, 409.

THE PRESENCE OF NITRITES IN THE AIR.

By GEORGE DEFREN, M.S.

Received May 9, 1896.

It is well known that the atmospheric air contains besides its main normal constituents, oxygen and nitrogen, admixtures in varying quantities of not only carbon dioxide and aqueous vapor, but, especially in the neighborhood of cities,[1] ammonia and various gases arising from industrial processes and resulting from the decomposition of animal and vegetable life.

The amounts of the impurities in the air may be very small. Ammonia exists sometimes to the extent of one part in 1,000,000. Ozone is said to be produced by electrical discharges during storms, by the breaking of waves on rocks, and other causes.[2] It has been shown[3] that when ammonia and ozone unite in the air they form hydrogen peroxide, ammonium nitrite, and ammonium nitrate. It has also been observed[4] that rain obtained during thunder storms contained more nitrites and nitrates than ordinary rain, from which we conclude that electrical discharges have some effect on this combination.

Aside from the above several investigations have been carried out to determine the origin of nitrites in the air and the possible effect of these nitrites on the human system. Böke[5] claims that when illuminating gas is burned the higher oxides of nitrogen are formed. W. V. Hoffmann[6] noticed that on combustion a gas was formed which had a reddish color and possessed an odor resembling

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[1] Mabery and Snyder: Jour. Am. Chem. Soc., **17**, 105.

[2] Gorup V. Besanez: Ann. Chem. Pharm., **161**, 232.

[3] Carius: Ber. deut. chem. Gesel., **8**, 1481.

[4] Goppelsröder: Jour. f. pract. Chem. [2], **4**, 139, 383; Smith: "On Air and Rain," 438; Bechi: Ber. deut. chem. Gesel., **8**, 1203.

[5] Chem. News, **22**, 57.

[6] Ber. deut. chem. Gesel., 1870, 658.

that of nitrous acid. E. A. Greete and P. Zoeller showed[1] by a conclusive investigation that when absolutely pure hydrogen was burned in pure air the condensed water formed showed an appreciable quantity of nitrous acid by the use of Griess' reagent. Berthelot[2] and Stohmann[3] found that by the combustion of nitrogenous bodies nitrous, nitric, and hyponitrous acids were formed. Leeds,[4] Wurster,[5] and Wright[6] also found nitrous acid as a product of the combustion of illuminating gas. Louis Ilosvay de N. Ilosva[7] made extensive researches on the subject, and came to the conclusion that the higher oxides of nitrogen were formed, but that no ozone nor hydrogen peroxide could be obtained. The presence of hydrogen peroxide in snow and rain[8] was due to other causes. Finally Alfred Von Bibra[9] investigated the question, and obtained considerable nitrous acid when illuminating gas was burned. Mabery and Snyder[10] have recently determined the amounts of nitrites found in air in various localities.

That headache and depression are experienced in crowded rooms is universally recognized, but the exact cause is not yet clearly determined. Formerly the presence of excessive carbon dioxide was supposed to be sufficient to account for the evil effects of bad air, but the researches of Hammond, Brown-Sequard and D'Arsonval,[11] and Merkel[12] claim the presence of a volatile organic poison in the fluid condensed from expired air. The results have, however, been contested by Dostre and Loye,[13] Russo Gilibert and Alessi,[14] Hofmann-Wellenhof,[15] Lehmann and Jessen,[16] Bergey, Mitchell, and Bil-

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[1] Ber. deut. chem. Gesel., 1877, 2144*b*.
[2] Comptes Rendus, **89**, 882.
[3] Jour. f. pract. Chem., **19**, 142.
[4] Am. Chem. Soc. J., 1884, 3; Chem. News, **49**, 237.
[5] Ber. deut. chem. Gesel., 1886, 3202, 3206.
[6] Chem. Soc. J., **37**, 422; Chem. News, **41**, 169; Chem. Ind., 1880, 207.
[7] Bull. soc. chem. d. Par., 1889, **2**, 377; Ber. deut. chem. Gesel., 1889, 793.
[8] Schöne: Ber. deut. chem. Gesel., **7**, 1695.
[9] Archiv f. Hygiene, **15**, 216.
[10] Jour. Am. Chem. Soc., **17**, 121.
[11] Comptes Rendus, 1888, 33; Société de Biol., 90, **99**, 108, 110.
[12] Archiv f. Hygiene, **15**, 1.
[13] Comptes Rendus, **88**, 91–99.
[14] Bolletino della Società d'igiene di Palermo, **88**, Nr. 9.
[15] Wiener Klinische Wochenschrift, **88**, Nr. 37.
[16] Archiv f. Hygiene, **10**, 267.

lings.[1] The latter named investigators claim that the injurious effects of air expired from the lungs appear to be due entirely to the diminution of oxygen or increase in carbon dioxide, or to a combination of these two factors, and state that it is improbable that the minute quantity of organic matter contained in expired air has any deleterious influence on men who inhale it in crowded rooms.

Even if no organic poison be exhaled from the lungs it is nevertheless a fact[2] that mice placed in closed receptacles and forced to breathe the expired air from other mice quickly died, showing the presence of some harmful substance. In direct connection with this observation stand the results obtained by Falck,[3] Husemann,[4] Charier,[5] Sucquet,[6] Desgranges,[7] Eulenberg,[8] Purcell,[9] Schmitz,[10] and Pott[11] on the poisonous qualities of nitrous acid.

With the more delicate methods of determining nitrites it has been proved that they exist in the air of inhabited rooms; hence the question naturally arises, Could the presence of *nitrites* in the air exert any influence in causing the effects hitherto wholly attributed to the carbonic acid gas? Ilosvay[12] claims that nitrites are exhaled from the lungs, and Wurster[13] and Cramer[14] maintain that the nitrites formed by the combustion of illuminating gas are the direct cause of the depressed feeling and uneasiness experienced in crowded rooms, while Rübner shows[15] that the humidity and rise of temperature possess an appreciable influence on the animal organism.

Comparatively little attention has been paid to the quantity of nitrites present in the air of inhabited rooms, and directions for these compounds are not available for the general student. The

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[1] Report to Smithsonian Institution; Nat. Acad. Science, April 16, 1895; Science, New Series, 1, 481, 482.

[2] Merkel: Loc. cit.

[3] Lehrbuch d. prakt. Toxicologie, 1880, S. 64.

[4] Lehrbuch d. Toxicologie.

[5] Bull. de la soc. med. d'emulat, 1823.

[6] Jour. d. méd., 1860.

[7] Jour. d. méd., T. 8.

[8] Die Lehre von d. gift. Gasen, 1865, S. 251.

[9] Med. a. Surg. Report, 1872, p. 313.

[10] Berl. kl. W. Schr., 1883, S. 428; 1884, S. 335.

[11] D. med. Woch., 1884, 29–30.

[12] Loc. cit. Ber., 798 c.; Bull. Soc. Chem., 388–391.

[13] Ber. deut. chem. Gesel., 1886, 3202, 3206.

[14] Jour. f. Gasbeleucht. u. Wasserversorg, 1891, 65; Archiv f. Hygiene, 10, 321.

[15] Archiv f. Hygiene, 16, 101.

object of the work here reported was to show that nitrites do exist in the air in appreciable though small quantity, that the amount of nitrites is varying under varying conditions, and that they increase in the same manner and under like circumstances as does carbon dioxide, thus indicating that they are products of combustion.

That nitrites do exist in the air of rooms is evident from the fact that 100 cc. of pure water treated with a mixture of 1 cc. hydrochloric acid (1 : 4), 2 cc. sulphanilic acid, and 2 cc. naphthylamine hydrochlorate solution, and exposed to the air, rapidly takes on a deep pink color, due to the absorption of nitrites from the air by the water, forming *a*-naphthylamine-azo-benzenesulphonic acid. For this reason the various "standards" used in estimating the amounts of nitrites in water are always freshly prepared on making an analysis to prevent as much as possible any liability of error in the determination.

The work described below was carried on in the Walker Building of the Massachusetts Institute of Technology. This structure has the reputation of being one of the best ventilated in the country, the air in the laboratories being completely changed once in seven minutes, so that some of the results obtained will be somewhat different from those possible in places where not so much attention is given to obtaining a good supply of fresh air.

The first experiment tried was to determine the rate of absorption of nitrites by water in various laboratories. 100 cc. of redistilled water were placed in each of three porcelain evaporating dishes (15 cm. in diameter), which gave in each case a superficial area of water exposed to the air of about 95 sq. cm. These were then allowed to stand for specified times in a room, and the amounts of nitrites absorbed by the water determined in the usual manner. The redistilled water used was that employed by the Massachusetts State Board of Health in making its various standards for determining the amounts of ammonia, nitrites, and nitrates, thus insuring the freedom of the water from these substances.

The absorption of nitrites by water in Room 36, Walker Building, was first determined. During the day on which this experiment was carried on no water analyses were in progress. One gas burner had been in use a part of the morning. In the latter part of the afternoon two lamps were burning till after five o'clock. An apparatus for furnishing hot water, heated by means of gas, was put into

service at 3.30 P.M. and left burning till after five o'clock. In this room there were also, on an average, three persons employed during the day.

The three porcelain dishes containing each 100 cc. of best redistilled water free from nitrites were placed side by side on a desk and exposed to the air for varying lengths of time, being then treated with the reagents named above — the depth of color produced by this means being compared to that of standard potassium nitrite solutions (1 cc. containing .0000001 gram nitrogen as nitrite) treated with the same reagents.

An analogous experiment was tried in Room 38 of the same building. During the morning one lamp had been burning one hour. Work was carried on by three persons during various portions of the day — they, however, not requiring the use of any gas burners. The three porcelain dishes were placed in position on a desk at two o'clock in the same manner as in the preceding case.

The third trial of the series was made with the air in Room 39. Four Bunsen burners had been in use all day, being turned out at five o'clock. Three students had been at work the greater part of the time, and at occasional intervals others were also present. The first two samples of water were placed in position at 2 P.M., and the third, which was exposed for seventeen hours, was placed in position at 4 P.M. The results of these series of experiments are given in the following table:

Room.	Hours of Exposure.			
	1.	2.	17.	19.
	cc. equivalent nitrite solution.			
36	2.5	3.5	—	57.2
38	3.5	8.5	—	72.7
39	8.0	13.5	84.2	—

On examining the above results we notice the following:

1. Even in the air of the best ventilated rooms where gas is burned nitrites exist.

2. Water exposed undisturbed to the air absorbs nitrites there existing.

3. The amount of nitrites so absorbed increases in almost direct proportion to the time the water is exposed, being also dependent, however, on the nature of the work carried on in the room.

4. On burning illuminating gas some of the nitrogenous constituents, though small in amount, are incompletely oxidized to nitrites.

The investigation next carried out was to make a quantitative estimation of the nitrites by volume by a method similar to that usually made use of in determining the quantity of carbon dioxide in the air of buildings. Two large bottles, the capacities of which were known, were placed side by side, and the air to be analyzed was drawn into them, using suction, one tube reaching nearly to the bottom of the bottle. They were then tightly closed with rubber stoppers and taken to the room where they were to be tested. 100 cc. best redistilled water free from nitrites were then introduced, the bottles allowed to stand, with occasional shaking, for more than twelve hours — in some cases for as many as twenty-four hours — before analysis. The water was then tested for nitrites in the usual manner.

Two samples of air from Room 36 were taken at 3.30 P.M. Fifteen lamps had been in use for about two hours. Three persons were employed during the day in this laboratory.

Two samples of air were also taken from Room 38 at nine o'clock in the morning. During the night preceding the room had been unoccupied, and no lamps had been in use up to the time of taking the samples. The bottles with 100 cc. water were allowed to stand until next morning and then analyzed for nitrites.

Two samples of air from Room 39 were taken at the same time as the preceding under the same conditions.

During the afternoon (at 3.30) two other samples of air were taken from this room in order to see whether any variation had taken place in the amounts of nitrites present. The samples were collected as in the previous cases. Eight Bunsen burners had been in use since 9 A.M., and were still burning at the time the air was taken for analysis. Three persons were employed in this laboratory during the day.

The amounts of nitrites absorbed by the water were determined in the usual manner. To see whether all the nitrites had been absorbed from the air in these bottles a little nitrite-free water was introduced after the above test. This water gave only a very faint coloration when treated with Griess' reagent, proving that nearly all the nitrite had been removed.

The temperature of the air was 20° C. at the time the analyses were made, and the barometric pressure was 758 mm.

The results obtained are as follows, the nitrogen equivalent being calculated as nitrous anhydride:

Room.	Time of taking sample.	Capacity bottle. cc.	cc. of nitrite equivalent.	Parts N_2O_3 in 10,000 air.
38	9 A.M.	8,980	8.5	.0140
38	9 A.M.	8,870	8.3	.0138
36	3.30 P.M.	8,980	19.5	.0319
36	3.30 P.M.	8,870	18.9	.0315
39	9 A.M.	8,870	24.6	.0408
39	9 A.M.	8,320	25.7	.0456
39	3.30 P.M.	8,870	43.2	.0690
39	3.30 P.M.	8,320	40.0	.0707

On inspecting the above results we see that (1) in the air of rooms the amount of nitrites is, as a rule, very small, on a clear day as little as .014 part in 10,000 parts air having been found; (2) the burning of illuminating gas and the presence of people seem to cause an increase in the quantity of nitrites present in the air.

Reference has been made as to the possibility of persons being a factor in causing the increase in quantity of nitrites in the air. That nitrites are formed through human metabolism is evidenced by the fact that the water in which the hands are washed give, on the addition of Griess' reagent, a very strong test for nitrites.

Trial was made to ascertain whether during the breathing process of man nitrites are exhaled. To this end 100 cc. of redistilled water were placed in a large test tube and exhaled air blown through this water from the lungs for five minutes. The water was then treated for nitrites in the usual manner. No pink-colored solution was formed, thus showing that expired air on passing through pure water does not give an indication of nitrites. This circumstance does not, however, prove conclusively that nitrites are absent in air which has passed through the lungs. There is a great probability that air containing a small amount of nitrite in the presence of a comparatively great quantity of oxygen on passing through water oxidizes these nitrites

to nitrates, or even decomposes them to nitrogen. That this is evidently so is seen from the fact that a stream of air drawn through pure water by means of suction also failed to give any indication of nitrites, though water left exposed, undisturbed in this same air, gave a very decided test.

It has also been mentioned that rain water obtained during a thunder shower contained more nitrogen as nitrite and nitrate[1] than rain tested when there were no electrical discharges in the atmosphere. It seemed, therefore, probable that the larger part of the nitrites and nitrates were washed from the air during a rain storm. This was proved to be the case, for two porcelain dishes, containing each 100 cc. of water, absorbed nitrites equivalent to 10 and 11 "standards," respectively, just before a rain storm. Immediately after the rain ceased one dish, exposed for one hour, gave an indication of 0.2 "standard," while another gave 0.4 "standard," showing that the air is very thoroughly washed during a heavy fall of rain.

It will be seen from the above that the results which I have obtained, though not numerous, deal yet with a subject hitherto little considered. Some of the determinations do not directly confirm what I had expected. Further experiment may lead to definite results, and although it is my intention to continue the investigation, I also hope that this fragmentary presentation may stimulate others to further work on the subject.

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[1] Loc. cit. (See above.)

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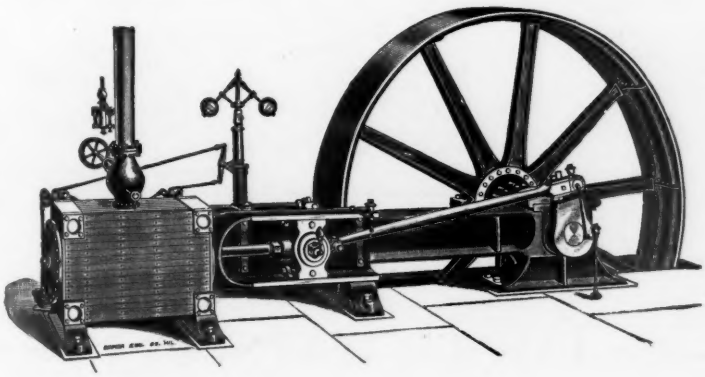

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